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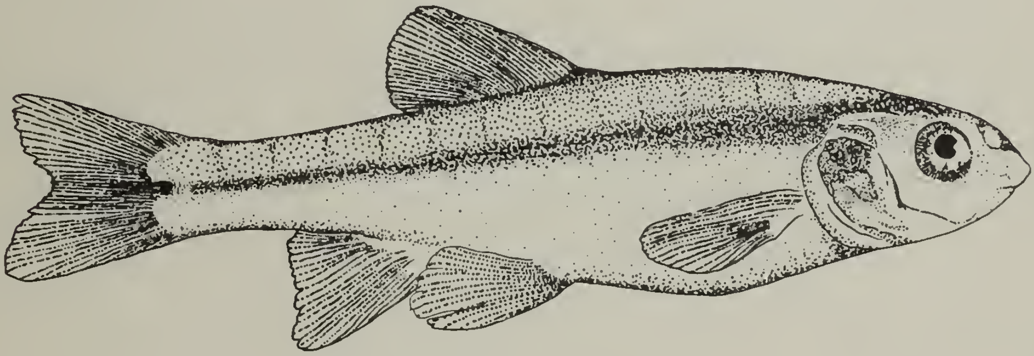
AQUATIC INVENTORY OF THE BILL WILLIAMS AND HASSAYAMPA DRAINAGES, MARICOPA, YAVAPAI, AND YUMA COUNTIES, ARIZONA

· U.S. Bureau of Land Management · Phoenix District Office ·



William G. Kepner ······· Aquatic Ecologist ······· September 1980

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Cover - Longfin dace (<u>Agosia</u> <u>chrysogaster</u>) by Lauren M. Porzer.
Male above and female below.

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AQUATIC INVENTORY OF THE BILL WILLIAMS AND HASSAYAMPA DRAINAGES, MARICOPA, YAVAPAI, AND YUMA COUNTIES, ARIZONA

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by William G. Kepner
Aquatic Ecologist
U.S. Bureau of Land Management
Phoenix District Office
September 1980

ABSTRACT

The Bill Williams and Hassayampa river drainages in west-central Arizona were surveyed during the winter and spring of 1980. The purpose of the study was to provide aquatic habitat and water quality baseline data for management planning of aquatic resources on public lands. Included in this report are descriptions of existing aquatic habitats, analyses of water quality, and distribution and quantification of aquatic invertebrate and fish populations. Chemical and physical water quality was generally within acceptable state and federal standards for surface waters, except in local situations involving copper mining operations. Quantitative sampling of macroinvertebrate communities revealed a general paucity of invertebrates. Surber invertebrate samples were largely dominated by chironomid dipterans. Museum records combined with field collections indicate at least 20 species of fish collectively occur over both drainages. More than 84% of the total fishes collected were native species, of which longfin dace (*Agosia chrysogaster*) were numerically dominant. Of four habitat types analyzed, backwaters supported the highest densities of both native and introduced fish. Riffles were least productive, but were found to provide preferred habitat for certain species of fish, *i.e.* Gila mountain-sucker (*Pantosteus clarki*). Management recommendations designed to enhance and maintain aquatic resources on the Harcuvar, Vulture, and Skull Valley planning units are discussed based on inventory data.

ACKNOWLEDGMENTS

Completion of the aquatic inventory was made possible through the efforts of several individuals to whom I wish to express my sincere appreciation. In particular, I wish to acknowledge David T. Shaffer for his assistance in the field collections and analysis of the data. I also would like to acknowledge the help Scott C. Belfit, Murry R. Williams, and John A. Gray for their field assistance. Dennis M. Kubly (Arizona State University, Tempe) is acknowledged for his assistance with the aquatic insect taxonomy. I am grateful for the helpful suggestions and thoughtful criticisms I received from Dr. W. L. Minckley (Arizona State University), Dr. J. N. Rinne (USDA Rocky Mountain Forest and Range Experiment Station, Tempe), Dr. R. M. McNatt (USFW Region 2, Albuquerque), and W. Silvey (Arizona Game and Fish Department, Phoenix) in their critical review of this paper. Finally, I wish to thank Lauren M. Porzer (BLM, Phoenix District Office) for her preparation of the figures included in the text.

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CONVERSION TABLE

Factors for conversion of International Standard Units (SI).

Metric	Multiply by	English Units
Millimeters (mm)	.0394	Inches (in)
Centimeters (cm)	.3937	Inches (in)
Meters (m)	3.2808	Feet (ft)
Kilometers (km)	.6214	Miles (mi)
Hectares (ha)	2.4710	Acres (ac)
Square meters (m^2)	10.7636	Square feet (ft^2)
Square kilometers (km^2)	.3831	Square miles (mi^2)
Hectare-meters (ha-m)	8.1071	Acre-feet (ac-ft)
Cubic meters/second (m^3/sec)	35.3144	Cubic feet/second (cfs)
Grams/square meter (g/m^2)	8.9219	Pounds/acre (lb/ac)
Milligrams/liter (mg/l)	1.0	Parts per million (ppm)
°C	1.8C + 32	°F

INTRODUCTION

In compliance with a 1973 Federal District Court decision (Natural Resources Defense Council vs. USDI Bureau of Land Management [BLM]), more than 5-million hectares (ha) of public land in Arizona are to be inventoried for wildlife and aquatic resources by 1988. The BLM must prepare 212 separate Environmental Impact Statements (EIS) under the provisions of the National Environmental Policy Act (1970) and must identify occurrence of vertebrate and invertebrate populations, and factors influencing their distribution, abundance, and diversity.

It was the purpose of this study to supplement previous work completed for the Bill Williams drainage (Kepner 1979), in addition to describing the aquatic resources of the Hassayampa River drainage. Information provided from this study will be summarized in an EIS and incorporated into various management approaches to aquatic systems on public lands.

DESCRIPTION OF THE STUDY AREA

An aquatic inventory was completed during winter and spring 1980 for perennial drainages of the BLM Harcuvar, Vulture, and Skull Valley planning units in Yuma, Maricopa, and Yavapai counties, Arizona (Fig. 1).

The Bill Williams and Hassayampa rivers collectively drain more than 17,951 square kilometers (km^2) in west-central Arizona (Fig.2). Both rivers are major tributaries of the Colorado River system and are characterized by riffle, pool, run, and backwater habitats.

The Bill Williams and Hassayampa drainages are included in the Southwestern Section of Arizona with regard to climatic pattern (Sellers and Hill 1974). Headwaters of both basins are located in the more mesic Northwest and Central physiographic sections. Lower reaches of the study area are characterized by a warm, semiarid climate. Annual precipitation is variable due to differences in topography, elevation, and latitude, but generally follows the bimodal pattern of winter and summer precipitation separated by relatively dry periods of spring and autumn drought (Lowe 1964). Maximum precipitation occurs during winter months when frontal storms enter the state from the northwest. Winter storms generally last for several days and distribute moisture over large geographic areas. Snow is common above elevations of 1,524 meters (m) from mid-November and rare after the first of May (Wendt *et al.* 1976). Summer rainfall is associated with the influx of moist tropical air masses which enter the state from the south. Unlike winter precipitation, summer thunderstorms are characterized by scattered rainfall of high intensity and short duration.

Stream discharge, like annual precipitation, typically follows the bimodal hydrological cycle (Fig. 3 and 4). Desert streams within the study area are often reduced to intermittent reaches during spring and autumn drought and subject to flash flooding throughout winter and late summer. Flash flooding is generally a short-lived phenomenon capable of transporting vast quantities of inorganic material and organic debris (Fisher and Minckley 1978), and effecting major channel changes.

Currents, excluding flooding events, were swift, averaging greater than 0.76 ± 0.3 m/sec 1/. Channel widths were constricted in headwater areas but averaged 12.4 ± 11.7 m overall (Table 1). Riffles and runs were typically shallow, 0.18 ± 0.14 m. Pools as deep as 3.2 m occurred along cliff faces or where banks were undercut.

Bottom materials varied with stream gradient. Boulders (> 30.5 cm diameter) and rubble (15.2 - 30.5 cm) were prevalent in the headwaters where gradients were steepest (>1.5°). On lower reaches where gradient was reduced to 1.0° or less, unstabilized sand (0.006 - 0.2 cm) and gravel (0.21 - 6.4 cm) became the dominant bottom types. Mean stream gradient was 1.0 ± 0.5°. Banks along the drainageways were often cut and sometimes undercut, but stabilized by rooted vegetation, *e.g.* Bermuda grass (*Cynodon dactylon*) and seep willow (*Baccharis salicifolia*).

1/ Means followed by ± one standard deviation, as used throughout text and tables.

Fig. 1. Location of the Harcuvar, Vulture, and Skull Valley planning units, Yuma, Maricopa, and Yavapai counties, Arizona.

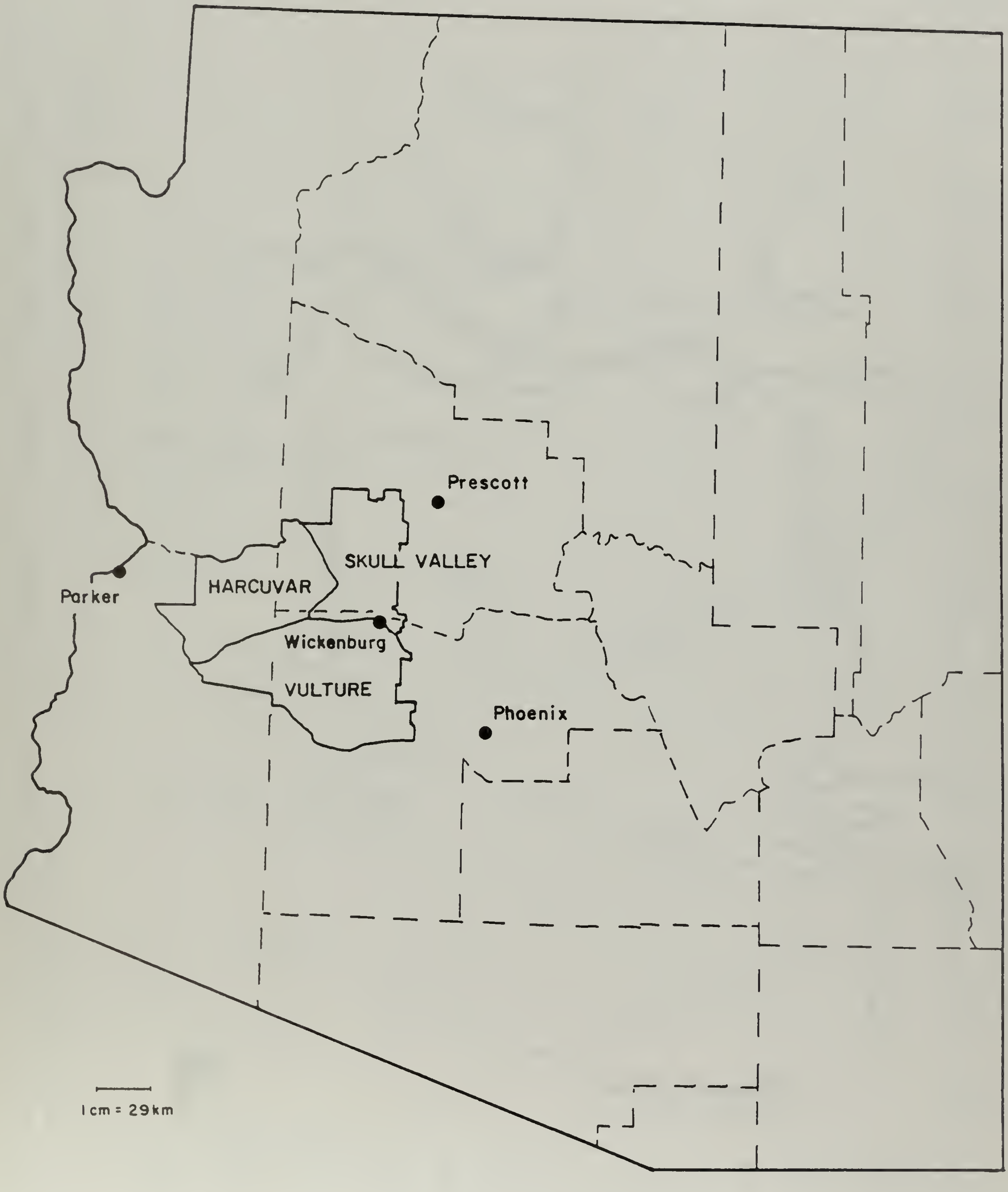


Fig. 2. Bill Williams and Hassayampa drainages, west-central Arizona.

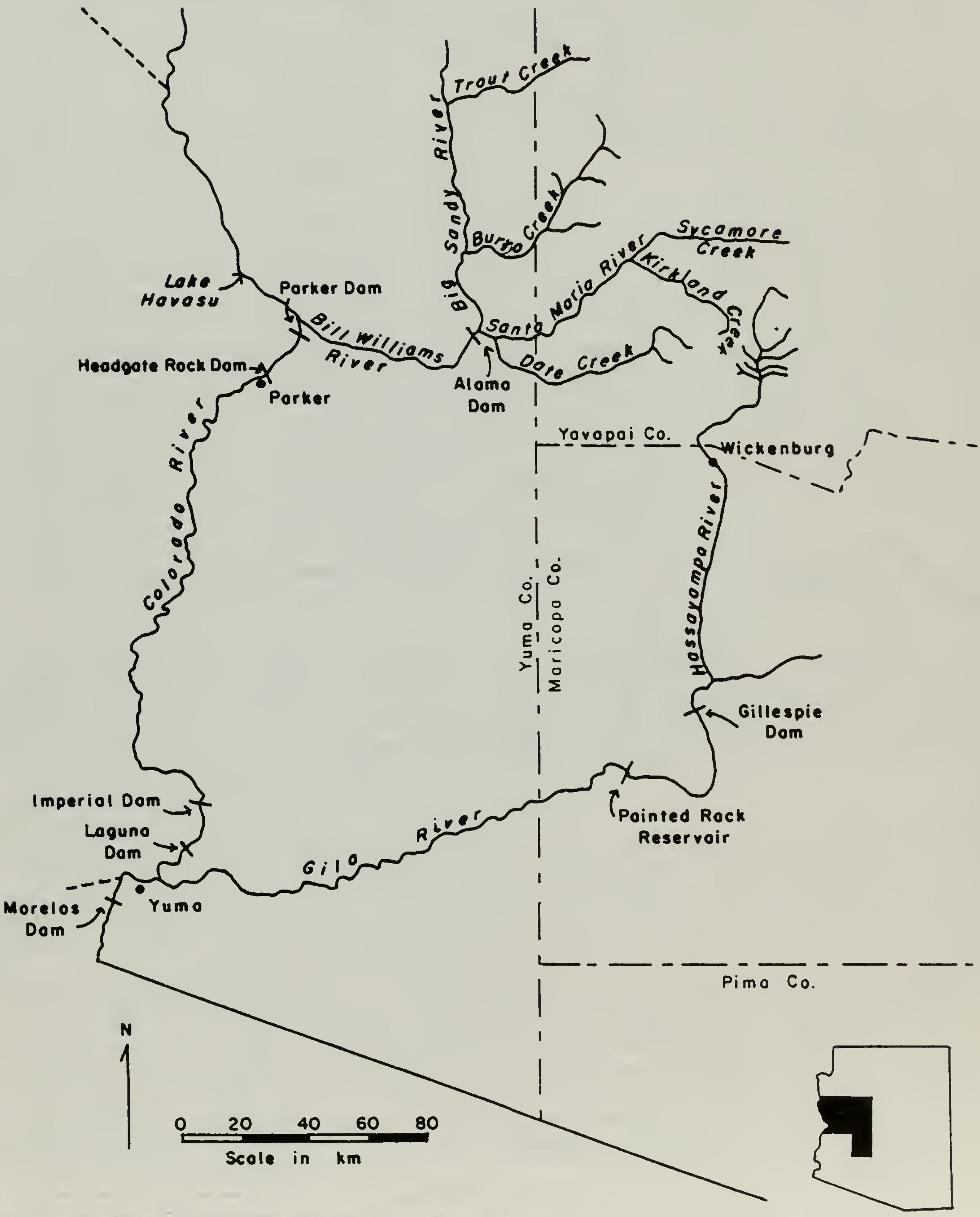


Fig. 3. Monthly patterns of precipitation and discharge for the Bill Williams River, Arizona (Sellers and Hill 1974, USGS 1979).

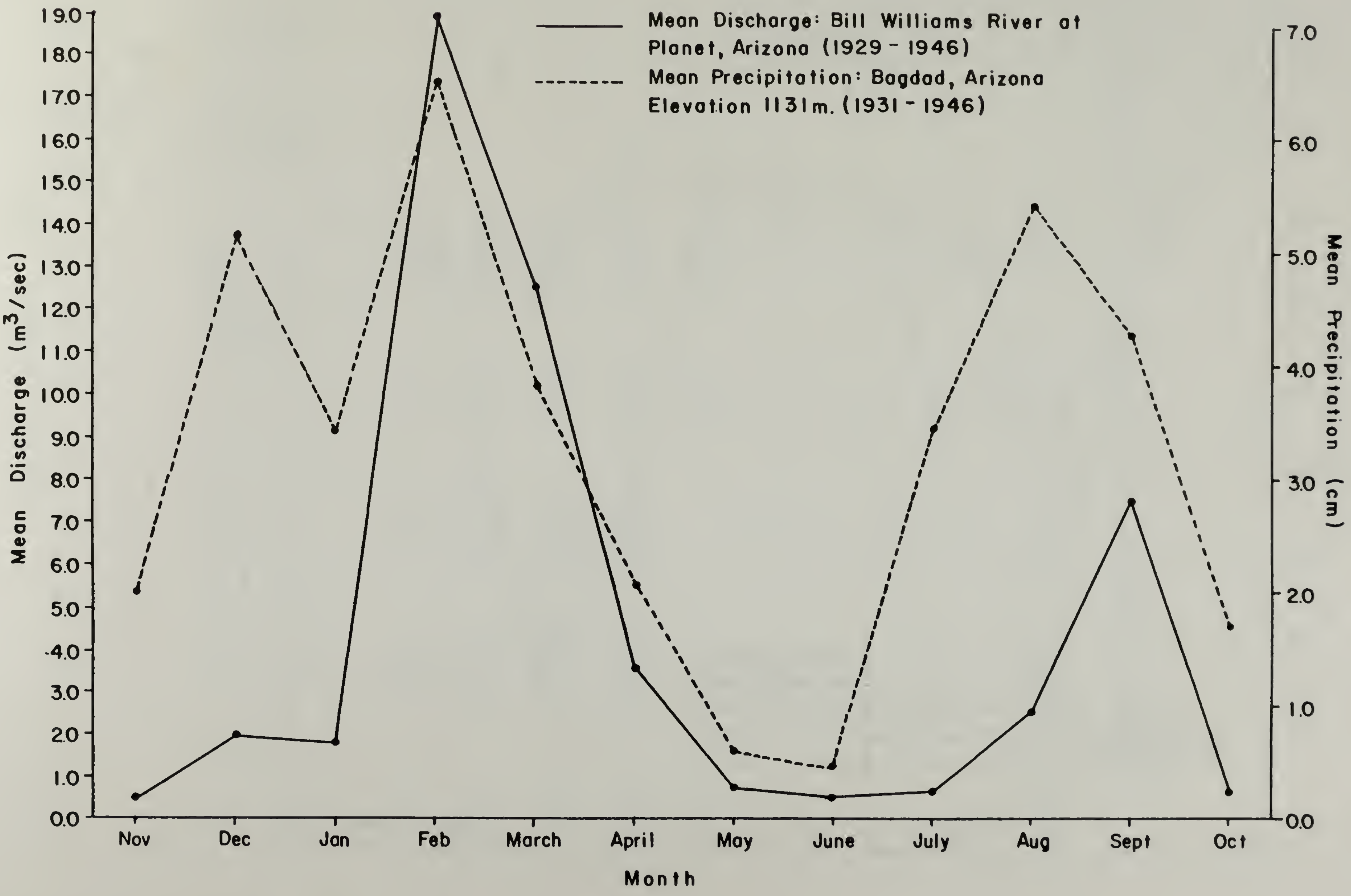


Fig. 4. Monthly patterns of precipitation and discharge for the Hassayampa River, Arizona (Sellers and Hill 1974, USGS 1979).

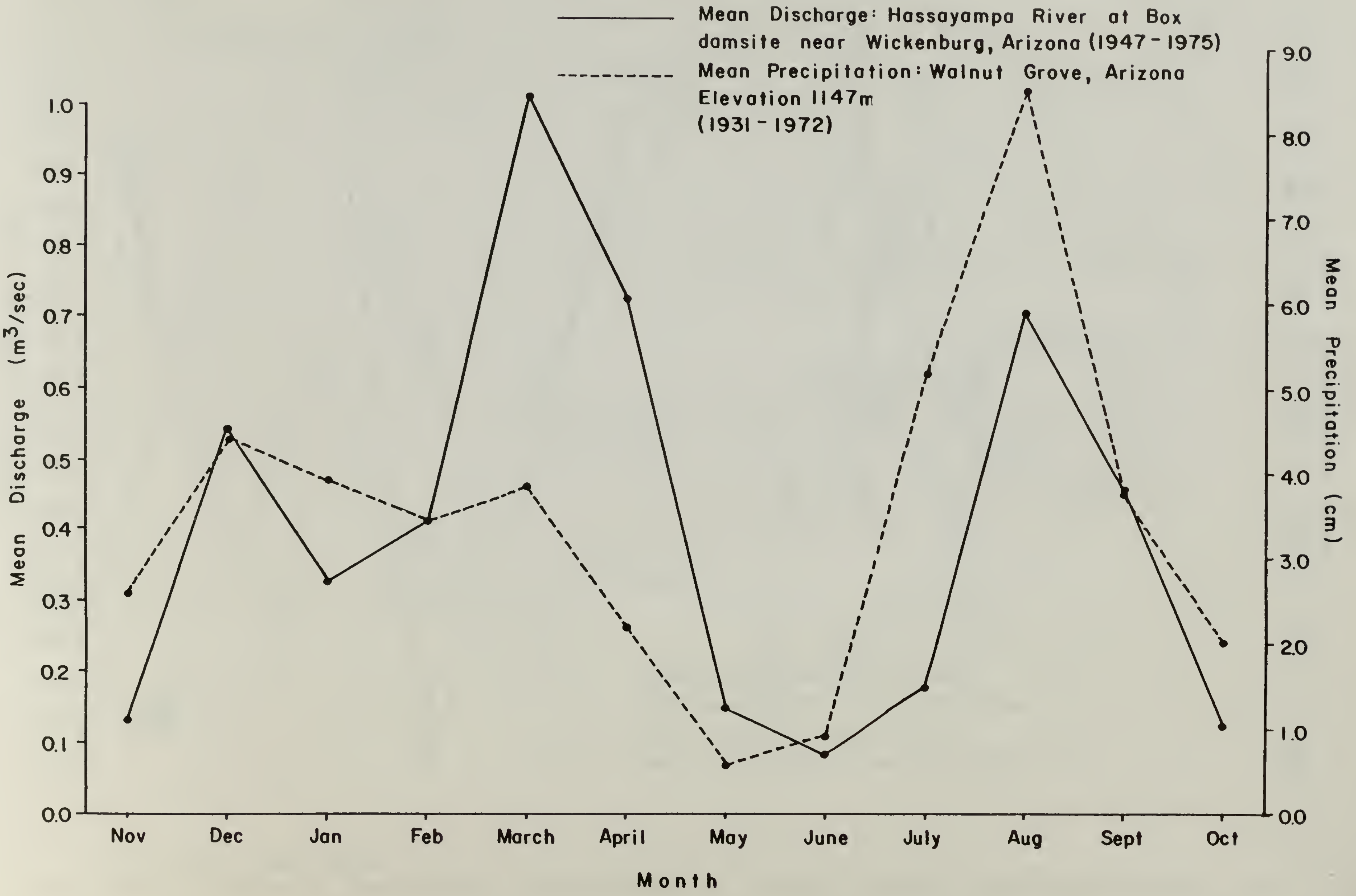


TABLE 1

Physical features of the Bill Williams and Hassayampa River drainages, west-central Arizona. Data include absolute values, means ± one standard deviation, and ranges (in parentheses).

Parameter	Date Creek	Kirkland Creek	Bill Williams River	Hassayampa River	Total
Drainage area (km^2)	648	1,129	14,141	3,810	17,951
Mean discharge (m^3/sec)	0.07 1/	0.20 3/	0.54 2/	0.40 2/	-
Record high discharge (m^3/sec)	39.6 1/	223 3/	2,970 3/	1,640 3/	-
Record low discharge (m^3/sec)	0 1/	0 3/	0 3/	0 3/	-
Stream-km sampled	21.3	49.7	25.3	109.2	205.5
Sampling interval (km)	1.8±1.1	4.3±1.7	6.3±1.2	3.9±1	3.7±1.7
Mean width (m)	15.9±10.2 (4-34.3)	8.2±6.1 (2.5-16.9)	-	12.5±14 (1.2-52.4)	12.4±11.7 (1.2-52.4)
Mean depth (m)	0.08±0.03 (0.03-0.14)	0.19±0.13 (0.05-0.52)	0.2±0.11 (0.14-0.39)	0.18±0.09 (0.07-0.39)	0.18±0.14 (0.03-0.52)
Mean stream gradient (°)	0.75±0.28 (0.5-1.3)	1.04±0.56 (0.5-2)	0.68±0.44 (0.25-1.25)	1.21±0.49 (0.35-2.25)	1.04±0.5 (0.25-2.25)
Mean stream velocity (m/sec)	0.72±0.19 (0.48-1.16)	0.67±0.42 (0-1.57)	0.67±0.17 (0.47-0.85)	0.83±0.28 (0.35-1.25)	0.76±0.3 (0-1.57)
Mean percent cover	8.2±10.9 (0-37)	14.2±14.9 (0-45.5)	18.6±26.3 (0-56)	15.9±25.3 (0-99.9)	14.2±21 (0-99.9)
N	14	14	5	33	66

1/ USGS 1954. Compilation of Records of Surface Waters of the United States through September 1950. Part 9, Colorado River Basin, WSP 1313.

2/ USGS 1979a. Statistical Summaries of Arizona Streamflow Data. Water-Resources Investigations 79-5.

3/ USGS 1979b. Water Resources Data for Arizona, Water Year 1978. Water-Data Report AZ-78-1.

Detailed information for the Bill Williams River below Alamo Dam, Date and Kirkland creeks, and the Hassayampa River and its perennial tributaries is summarized as follows.

Bill Williams River

Flow in the Bill Williams River below Alamo Dam results from either release or overflow from the reservoir (spillway elevation 376 m) and passes west 56 km before entering the Colorado River (elevation 137 m) northeast of Parker, Arizona. The upper basin drains more than 12,250 km^2 above the dam and an additional 1,891 km^2 below (F. Boner, USGS, Arizona District Office, Tucson, pers. comm.)

Maximum storage capactiy of Alamo Lake is 1,290 hectare-meters (ha-m) (USGS 1976b); surface area varies from 202 ha at minimum pool to 5,382 ha at capacity. Following regulation of Alamo Dam (28 March 1969) by the U.S. Army Corps of Engineers for flood control, mean annual discharge declined from 4.2 ± 4.8 m^3/sec (Gage 4265, 50 km downstream from Alamo Dam at Planet Ranch, 1929 - 1946) to 2.6 ± 4 m^3/sec (USGS 1979a) and averaged 76 zero-flow days a year (Woodward-Clyde Consultants, 1978). Reduced flows may also be attributable to diversions in the upper basin for mining and irrigation. Normal flow below the dam now averages 0.5 ± 0.6 m^3/sec (USGS 1979a, period of record 1969-1972, 1974-1975), except in times of excess runoff. Prior to impoundment, the highest recorded discharge measured 2,970 m^3/sec in February of 1937 (USGS 1979b).

The Bill Williams River below Alamo Dam dissects Precambrian metamorphic rocks, primarily schist of the Rawhide Mountains and gneiss of the Buckskin Mountains. Further downstream, waters flow across loosely consolidated sand and gravel sediments dating from late Pliocene or early Pleistocene.

Soils are shallow and rocky outside the floodplain; slopes are typically 15 to 30 percent (Richmond and Richardson 1974). Stream substrate has been formed in both old and recent mixed alluvium on dissected terraces and fans. The river is characterized as a broad, shallow, sand-bottomed run with numerous backwaters. Pools and riffles are rare. Mean depth and gradient are equal to 0.2 ± 0.1 m and 0.68 ± 0.44°, respectively (Table 1).

Non-riparian vegetation adjacent to the Bill Williams River includes microphyllous trees and shrubs, cacti, and annual grasses and forbs common to the lower Sonoran Desert (Lowe 1964). Riparian vegetation is dominated by mesquite (*Prosopis velutina*) and saltcedar (*Tamarix chinensis*). Dense cottonwood/willow (*Populus fremontii*/*Salix gooddingii*) woodlands occur in two areas, the El Paso Natural Gas Pipeline and at Planet Ranch.

Mean air temperature is 19.6 to 21.8 °C and average annual precipitation 10 to 20 cm (Richmond and Richardson 1974).

Date Creek

Date Creek originates in older Precambrian granite of the Weaver and Date Creek mountains (elevation 1792 m). At lower elevations it flows across recent sedimentary deposits, mostly alluvial sand and gravel sediments of the Pleistocene and Holocene.

Date Creek drains more than 648 km^2 (F. Boner, USGS, Arizona District Office, Tucson, pers. comm.) before entering the Santa Maria River east of Alamo Lake (elevation 376 m). The creek is characterized as a narrow (15.9 ± 10.2 m), sandy run where pools and backwaters are absent and riffles rare. Gradient of the stream channel averages 0.75 ± 0.28° and depths are shallow, 0.08 ± 0.03 m (Table 1).

Mean discharge at former USGS gaging station No. 652 (1939 - 1944) equaled 0.066 m^3/sec, but varied from no flow situations to maximum flows of 39.6 m^3/sec (14 March 1941). Flash flooding was normally associated with the winter precipitation peak, January through March (USGS 1954). Soils in headwater areas are steep and shallow, having been formed in place over bedrock or weathered from colluvial materials. Soils are coarse-textured and rock outcrop common. Downstream, Date Creek passes over deep, gravelly soils formed in old alluvial fans, mainly from granitic parent rocks. Soils within the floodplain are moderately permeable with little or no relief (1 to 8 percent slope)(Chamberlin and Richardson 1974).

Vegetation above the floodplain varies from desert grassland communities at the higher elevations to creosote bush/Joshua tree (*Larrea tridentata*/*Yucca brevifolia*) flats on the desert floor. Riparian vegetation is sparse with the exception of cottonwood/willow galleries which occur along perennial reaches of the creek.

Mean air temperature varies between 15.7 to 20.2 °C and average annual precipitation between 20 and 30.5 cm (Chamberlin and Richardson 1974)

Kirkland Creek

Kirkland Creek originates at the confluence of Model and Miller creeks in Peeples Valley (elevation 1341 m) and drains more than 1,129 km^2 (F. Boner, USGS, Arizona District Office, Tucson, pers. comm.) before forming the Santa Maria River at its confluence with Sycamore Creek (elevation 800 m). The headwaters drain cobbly-loam granitic soils of the Weaver Mountains and later pass over shallow, medium-textured soils scattered between tertiary basalt outcrops. Northwest of U.S. Highway 89, Kirkland Creek flows over deep soils formed in mixed recent alluvium and lacustrine deposits underlain by weathered and fractured bedrock. Soils are nearly level along floodplain bottoms and gently sloping on alluvial fans between granite or schist hills and mountains.

Mean discharge at USGS Gaging Station No. 4244 (1973 - 1978) located 2.7 km southwest of Kirkland, Arizona was 0.201 m^3/sec (USGS 1979b). Discharge varied between periods of little flow, 0.031 m^3/sec, to maximum discharges of 223 m^3/sec (1 March 1978).

Riffles, runs, pools, and backwaters are well represented, providing a diversity of habitats. Average width of Kirkland Creek is 8.2 ± 6.1 m and mean gradient 1.0 ± 0.6°. Mean depth is 0.19 ± 0.13 m (Table 1).

Non-riparian vegetation varied from chaparral at elevations above 1,219 m to palo verde/saguaro (*Cercidium microphyllum*/*Cereus giganteus*) desertscrub near the confluence of Kirkland and Sycamore Creeks. Riparian vegetation consists of cottonwood/willow stands with bosque species, *e.g.* mesquite and catclaw (*Acacia greggii*), on upper terraces of the floodplain.

Mean air temperatures range from 10.6 to 14.6 °C and annual precipitation averages between 30.5 and 50.8 cm (Wendt *et al.* 1976).

Hassayampa River

The Hassayampa River originates on Mt. Davis of the Bradshaw Mountains in the Prescott National Forest (elevation 2,256 m). The Hassayampa River and its perennial tributaries collectively drain more than 3,810 km^2 before entering the Gila River (elevation 238 m) 4.8 km east of Arlington, Arizona (USGS 1979b).

Soils in the headwater areas are steep and shallow over weathered Precambrian granite and schist. Vegetation consisted of mixed stands of Gambel oak (*Quercus gambelii*), ponderosa pine (*Pinus ponderosa*), and other conifers at elevations above 1,676 m, and chaparral species, *e.g.* scrub oak (*Quercus turbinella*) below. Soils on the fans below the Bradshaw Mountains are deeper in profile and consist of sandy and gravelly alluvia that are nearly level along the stream bottom. They have been formed in late Tertiary (Pliocene) sedimentary deposits weathered from a variety of geologic materials. Below Wagoner, Arizona, the river enters a granite gorge where soils become a series of very shallow weathered materials over steep mountainsides. Soils are typically rocky and included areas of outcropping.

Below Wickenburg the river flows next to rhyolitic cliffs and across recent Quaternary alluvial sediments to its mouth at the Gila River. Soils are deep and slopes generally less than one percent (Hartman 1973). Vegetation (saltcedar, mesquite, and creosote bush) is dense in areas where the water table is relatively near the surface. Riparian vegetation in the upper reaches of the river includes various broadleaf species such as sycamore (*Plantanus wrightii*), velvet ash (*Fraxinus pennsylvanica*), and Arizona walnut (*Juglans major*), but is mostly dominated by cottonwood and Goodding willow. The drainage area is characterized by low order desert streams with riffles, pools, runs, and backwaters. Bottom materials present a mix of particle-sizes where large substrata, *i.e.* boulder, rubble, and cobble, are prevalent in headwater areas and unstabilized sand and gravel dominant over the lower reaches. Stream gradients vary between 0.35 and 2.25° and average 1.21 ± 0.49°. Mean width and depth are 12.5 ± 14 m and 0.18 ± 0.09 m, respectively (Table 1).

In a 29-year period from 1946 to 1975, average discharge at USGS Gaging Station No. 5155 (located in Box Canyon 8.8 km northeast of Wickenburg) was 0.4 ± 0.5 m^3/sec (USGS 1979a). Discharge may vary from periods of no flow to maximum flows of 1,640 m^3/sec (5 September 1970).

Mean air temperatures vary from 6.2 and 11.2 °C at the higher elevations to between 20.7 and 23.5 °C on the desert floor. Annual precipitation exceeds 45.7 cm in the headwaters of the upper basin and averages between 12.7 and 22.9 cm along the lower reaches (Hartman 1973).

METHODS

More than 205 stream-kilometers of the Bill Williams and Hassayampa drainages, including federal, state, and private lands, were surveyed for biological and physicochemical information. Sixty-eight stations were positioned at roughly equivalent intervals (3.7 ± 1.7 km) depending upon access (Table 1). Specific station locations are given in Appendix 1. A 30.5 m reach was sampled at each station and was subsequently classified as either a riffle, run, pool, or backwater (Kepner 1979). Due to limitations of time, each station was sampled only once beginning 28 February 1980 and ending 16 May 1980.

Physical features at each station were either subjectively described, *e.g.* bank and current types, or directly measured, *e.g.* depth, width, velocity, and stream gradient. Current velocity and instantaneous discharge were determined with a Pygmy (Model 625) current meter (Embody 1927, Robbins and Crawford 1954). Velocities were measured at 0.6 the depth below the surface to most closely approximate the mean in the vertical profile (Linsley *et al.* 1975). Stream gradients were determined through use of an Abney level; bottom types were visually estimated. Particle-sizes (Table 2) were categorized following modifications of Cummins (1962) and Hynes (1970). Description and condition of the riparian vegetative communities followed the most recent classification (Brown 1978, Brown *et al.* 1979). Overstory density was measured with a spherical densiometer (Lemmon 1956, 1957). Selected chemical/physical parameters were monitored at each station with a Hydrolab 6D Surveyor. The unit is equipped with direct readout for water temperature (°C), hydrogen ion concentration (pH), specific conductance as micromhos (mmho)/cm (corrected to 25 °C) and dissolved oxygen concentration (mg/l). Macronutrients (phosphate-phosphorus [PO_4 - P] and nitrate-nitrogen [NO_3 - N]) were analyzed in the field using a Bausch and Lomb, Mini 20 spectrophotometer. The Hydrolab was recalibrated each week to insure accuracy of the unit. Total dissolved solids (TDS) or filtrable residue were determined in the laboratory by evaporating filtered water samples at 103 °C to constant dryness (Lind 1979). In comparing TDS data with concurrent conductivities, a coefficient was empirically determined which related TDS to conductance. Thereafter, TDS values were determined directly in the field from conductivity data, thereby precluding further filter-evaporation procedures.

Benthic invertebrates were sampled with a Surber stream sampler (929 cm^2, 1,050 micron-mesh)(Surber 1937). Two Surber samples were collected at each station in either riffles or runs to quantitatively estimate macroinvertebrate population density and biomass (Needham and Usinger 1956). Samples were hand-picked in the field and preserved in 50% isopropanol. The organisms were returned to the laboratory to be sorted, identified, enumerated, and wet-weighed. Invertebrates were dried by blotting on absorbent paper and weighed on a Mettler electric analytical balance to the nearest 0.0001 gram (g). Caddisflies (Trichoptera) were weighed after excision from their cases. No corrections were made for weight change upon preservation and therefore wet-weights are considered to be relative rather

TABLE 2

Substrate particle-size classification. Modified from Cummins (1962) and Hynes (1970).

Bottom Type	Particle-size or Description (range in mm)
Sapropel	reduced organic sediment
Detritus	organic particulate matter
Clay	< 0.004
Silt	0.004 - 0.063
Sand	0.063 - 2
Gravel	2 - 64
Cobble	64 - 152
Rubble	152 - 305
Boulder	>305
Bedrock	exposed solid rock mass

than absolute. Wherever possible, specimens were identified to the species level. Each level of identification was considered as one taxon for diversity calculations (Wilhm and Dorris 1968) and for determining the total number of taxa per sample. Taxonomic references to identification included Usinger (1956), Edmondson (1959), Merritt and Cummins (1978), and Pennak (1978). Data are reported either as numbers or wet-weight per square meter (m^2).

Qualitative fish data was derived through review of published and unpublished reports prior to entering the field. Specifically, these included the distributions and records of Minckley (1973) and Silvey _et al_. (1981).

Fish were collected by 115 volt, A.C., backpack electrofishing equipment and 3.2 mm - mesh seines. Monofilament gill nets (3.8 cm - mesh) were used to survey Alamo Lake. Specimens were initially preserved in 10% formalin and later stored in 50% isopropanol. All fish were enumerated, measured to the nearest millimeter (mm) total length (TL), and weighed to the nearest 0.1 g on a triple beam balance. Lengths and weights were not corrected for changes due to preservation. Identifications followed Minckley (1973). All specimens were catalogued and retained as a voucher series to be deposited in the Collection of Fishes, Arizona State University, Tempe.

Fish population estimates were determined using the two-catch removal technique (Seber and Le Cren 1967) in which fish were removed and enumerated in two consecutive runs using electroshocking gear. Estimates were corrected for bias due to gear selectivity inherent to electrofishing (Junge and Libosvarsky 1965). Population estimates ($\hat{N}$) were judged to be close approximations of true N (Zippin 1956, 1958; Seber and Le Cren 1967). Data are reported as numbers and wet-weight per square meter.

Fish populations were further tested for independence over physical parameters for which there were continuous data. The Kolmogorov-Smirnov distribution-free test (Hollander and Wolfe 1973) was used to detect broad classes of dependency alternatives. For those situations where discrete, noncontinuous data existed, _e.g_. substrate classes and habitat types, fish populations (as actual fish/m^2) were tested for significance at the p=0.95 level using two nonparametric tests, Mann-Whitney U-test and Kruskal-Wallis test (Sokal and Rohlf 1969).

RESULTS AND DISCUSSION

Water Chemistry

Water quality was, with few exceptions, within levels outlined in federal (U.S. Environmental Protection Agency [USEPA] 1976) and state (Arizona Department of Health Services [ADHS] 1979) surface water standards (Table 3).

Water temperature during the winter/spring study period ranged from 7.0 to 23.5 °C. Summer water temperatures are obviously higher, with pronounced variation occurring in areas where streamside vegetation or other cover is lacking. Mean water temperature was 15.6 ± 4.3 °C with backwaters typically 1 to 2 °C warmer than mainstreams.

Turbidities were often undetectable over cobble/rubble riffles, yet in areas of unstabilized substrate, such as sand and gravel runs, waters were visibly turbid. During periods of high discharge, waters became loaded with suspended particles which entered the watercourse via sheet runoff.

Hydrogen ion concentration was consistently alkaline, averaging 8.0 ± 0.5. Hydrogen ion values ranged from 6.8 to 9.0 and were within recommended standards (6.5 to 9.0) for freshwater aquatic life (USEPA 1976, ADHS 1979). Some diurnal fluctuation was detected relative to photosynthetic activity of aquatic biota. Dissolved oxygen concentrations paralleled fluctuations in pH. Waters in the Bill Williams River below Alamo Dam were uniformly high in pH due to phytoplanktonic activity in the lake above (Table 3). During photosynthesis, phytoplankton reduce calcium by precipitation of carbonate and raise pH by removal of carbon dioxide, or in some cases, by production of hydroxl ions (Ruttner 1963).

Waters were well-oxygenated and averaged 98.38 ± 12.28% saturation (N=31). Dissolved oxygen concentrations varied diurnally, and inversely with temperature, but were consistently above the minimum level (6.0 mg/l) recommended for state fisheries (ADHS 1979). Dissolved oxygen ranged between 6 and 15 mg/l and averaged 10 ± 1.7 mg/l. No up- to downstream trends in oxygen concentration were detected.

Specific conductance is the reciprocal of electrical resistance which reflects the osmotic concentration of solutes. Conductance varied between 295 and 1,000 mmho/cm (at 25 °C) and averaged 512 ± 137 mmho/cm. Conductivity values were converted to TDS by empirically establishing a ratio between the two using filter-evaporation procedures for selected water samples. In lotic systems, TDS concentrations typically increase downstream as dissolved ions from the drainage basin are steadily added to the watercourse (Hynes 1970). Waters of the Bill Williams and Hassayampa rivers were dilute in headwater areas (<190 mg/l) and more concentrated in downstream reaches (up to 410 mg/l). Seasonal trends that follow variations in stream discharge and evapotranspiration rates are also to be expected (Hynes 1960). Values for TDS concentrations varied between 82 and 410 mg/l and averaged 241 ± 71 mg/l. Average TDS was below maximum levels recommended for surface waters (USDI 1968) and optimal fish production (McKirdy 1968), 500 and 400 mg/l, respectively. Although TDS was below recommended maxima,

TABLE 3

Physicochemical data for the Bill Williams and Hassayampa drainages, February through May, 1980.

Data represent mean ± one standard deviation with ranges in parentheses.

	Temperature (°C)	pH	Dissolved Oxygen (mg/1)	Specific Conductance (mmho/cm)	Total Dissolved Solids (mg/1)	TDS/Conductivity	Orthophosphate (mg/1)	Nitrate-Nitrogen (mg/1)
Date Creek (N=14)	15.8±2.3 (11-19.3)	7.9±0.1 (7.8-8.0)	9.9±0.8 (8-11)	417±50 (295-490)	187.7±22.5 (132.8-220.5)	0.45	0.6±0.61 (0.1-2.4)	1.21±1.57 (0-4.5)
Kirkland Creek (N=14)	15.3±3.5 (11-22)	7.9±0.4 (7-9)	10.1±1.6 (6-13)	694±186 (400-1000)	284.4±76.3 (164-410)	0.41	0.67±0.58 (0.14-2.4)	0.14±0.54 (0-2)
Bill Williams River (N=5)	16.2±3.1 (12.5-20.6)	8.4±0.2 (8.1-8.7)	11.8±2.6 (8.8-14.7)	338±9 (329-350)	84.4±2.2 (82.3-87.5)	0.25	0.5±0.17 (0.4-0.8)	0.23±0.05 (0.18-0.3)
Hassayampa River (N=33)	15.5±5.5 (7-23.5)	8±0.6 (6.8-9)	9.8±1.9 (7-15)	513±57 (350-650)	271±30.4 (185.5-344.5)	0.53	0.3±0.38 (0-1.3)	0.26±0.32 (0-1.15)
Total (N=66)	15.6±4.3 (7-23.5)	8±0.5 (6.8-9)	10±1.7 (6-15)	512±137 (295-1000)	241.2±70.9 (82.3-410)	0.47	0.46±0.49 (0-2.4)	0.44±0.87 (0-4.5)

it remained higher than the mean (120 mg/l) for rivers of the world (Livingstone 1963). Kirkland Creek had the highest concentrations of dissolved inorganic salts and organic residues. Specific conductance and TDS averaged 694 ± 186 mmho/cm and 284 ± 76 mg/l, respectively. In contrast, waters in the Bill Williams River below Alamo Dam were most dilute. Conductivity averaged 338 ± 9 mmho/cm and TDS 84 ± 2 mg/l. Fluctuations of TDS values in the Bill Williams River below the dam were thus ameliorated by Alamo Lake which acts as a settling basin and nutrient trap.

Macronutrients, phosphate-phosphorus and nitrate-nitrogen, generally decline up- to downstream in desert streams, due to assimilation by aquatic autotrophs (Grimm 1980). Dissolved PO_4, orthophosphate, is the only form of phosphorus which is immediately available for uptake by autotrophic plants. Desert streams are often highly mineralized and typically high in phosphate concentrations (Gibbs 1970, Hem 1970). During the study period, orthophosphates averaged 0.46 ± 0.49 mg/l and ranged from 0 to 2.4 mg/l. Although dissolved phosphate levels were not continuous throughout, orthophosphate was not perceived as the limiting nutrient to primary production. Kirkland Creek had the highest average orthophosphate levels, 0.67 ± 0.58 mg/l, presumably due to extensive inorganic phosphate stores located within the Tertiary basalts of the headwaters (Table 3). Orthophosphates in the Hassayampa River deviated from the general up- to downstream trend of autotrophic assimilation (Fig. 5). Elevated orthophosphate levels near Wickenburg (Station 50) reflect influence of fertilizers, livestock grazing, and irrigation wastewaters from adjacent agricultural lands and perhaps leachate from septic tanks and sanitary landfills from municipal sources.

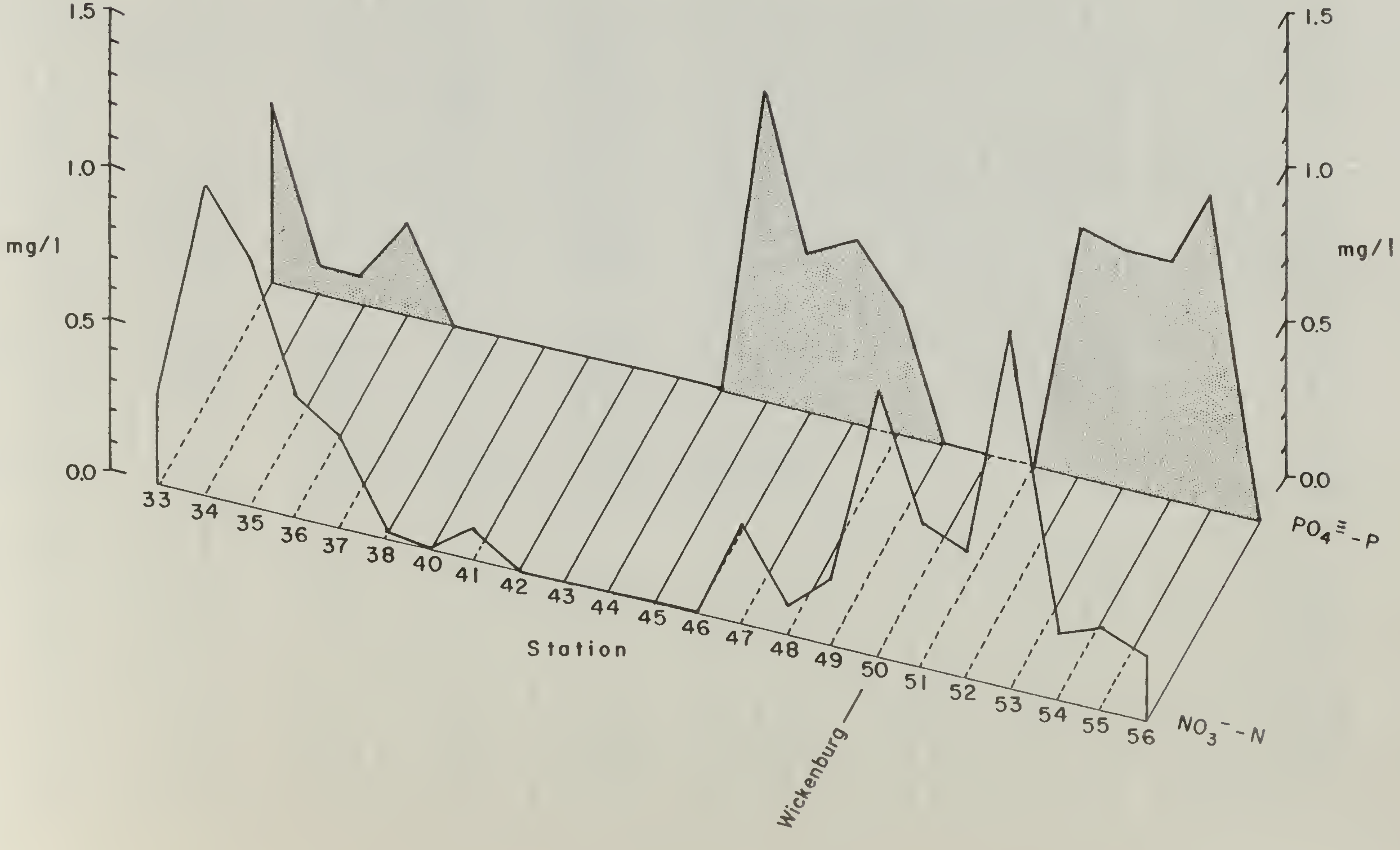
Although water quality standards for orthophosphates have not been established or applied to natural surface waters, if left unchecked problems of accelerated eutrophication could arise (USEPA 1976). Fortunately, situations involving nutrient loading in the Hassayampa are biologically neutralized by assimilation.

Nitrate-nitrogen is the most fully oxidized form of nitrogen in lotic waters and therefore the most available nitrogen source for stream autotrophs. During the present study, there was a rapid decline in NO_3 below headwater areas. Nitrate levels tended to be low 0.44 ± 0.87 mg/l and ranged from 0 to 4.5 mg/l (Table 3). Given the general lack of NO_3 - N and the rapid depletion of it, primary production may well be limited by the availability of N in the form of nitrate. Both nitrate and phosphate levels were also low in tributaries feeding mainstreams, 0.13 ± 0.26 mg/l and 0.14 ± 0.27 mg/l, respectively.

Peak nitrate concentrations in the Hassayampa River near Wickenburg were consistent with increases in phosphates, presumably for the same reasons (Fig. 5). Nevertheless, elevated nitrates presented no health hazard to human habitation since concentrations were significantly below the maximum level (10 mg/l) imposed on domestic water supplies (USEPA 1976).

Although toxic metals are widely distributed in their natural state, their entry into aquatic habitats has historically been aggravated by the mining industry. Mining activities and their associated contaminants (Cyprus-Bagdad

Fig. 5. Macronutrient levels of the Hassayampa mainstream, up- to downstream (April 1980).



Copper Mine, Anderson Uranium Mine) have previously been discussed for the upper basin of the Bill Williams River (Kepner 1979). Although the chemistry of heavy metals in natural waters, e.g. copper and zinc, is well documented in the literature, thallium (Tl) has rarely been studied.

Thallium is strongly concentrated in sulfide ores and therefore associated with mining activities involving economically important metals. It is particularly found in connection with copper mining operations processing chalcopyrite ($CuFeS_2$). In a study conducted by the Calspan Corporation (USEPA 1977), Tl was found to accumulate through the food chain at successive trophic levels. The concentration of metal in tissue samples was found to be more closely related to the concentration in bottom sediments than to ambient water levels. Higher trophic levels were found to have lower concentrations of toxic metals such that benthic organisms accumulated more than fish. Physiological response and mortality to biological concentration of Tl were not discussed.

The Planet Mine is a former copper mine (1966 to 1970) owned and operated by the Powdered Metals Corporation. It is located near Planet Wash, 1.2 km south of the Bill Williams River. In 1973 the Planet Mine was sampled for heavy metals and found to contain the highest Tl concentrations (5.1 mg/l) in the Southwest out of nine localities tested (USEPA 1977). In contrast, the Bill Williams River above Planet Wash recorded less than 0.11 mg/l thallium. Problems arise when particulate matter from stored wastes leach into the Bill Williams River during flood erosion. Fortunately, the dissolved metal concentrations appear to be ameliorated by chloride ions. A halogen complex (ligand) forms that absorbs or precipitates the soluble thallous ion. This does not prevent uptake by detritivores however, as evidenced by high tissue concentrations in benthic organisms (USEPA 1977).

Other problems associated with dissolved metals were identified in the vicinity of the Zonia Copper Mine, 12.9 km northeast of Yarnell, Arizona. The open-pit mine is owned by the McAlester Fuel Company (McAlester, Oklahoma) and located on the headwaters of French Gulch.

French Gulch is an intermittent drainage which originates in the Weaver Mountains (elevation 1,463 m) and flows approximately 17.7 km before entering the Hassayampa River 4.8 km below Walnut Grove (elevation 1,050 m). During a cooperative investigation with the Ambient Water Quality Unit of ADHS, French Gulch was sampled below the mine at 3.2 ± 2.9 km intervals (Table 4). The Hassayampa River above its confluence with French Gulch was sampled as a control station. Although the *in situ* leaching operation has been discontinued, leachate continues to escape into French Gulch from the mine. Cobble/gravel substrate in the upper reaches was buried up to 2 cm thick with copper sulfate precipitant. Sulfate levels were recorded up to 2,175 mg/l, considerably higher than the 90 mg/l limit considered optimal for fish and other aquatic life by McKirdy (1968). Sulfate levels of 2,104 mg/l have been reported to cause progressive weakening and death in cattle (McKee and Wolf 1963). Two metals, copper and manganese, were found at levels which exceeded state standards for ambient waters (ADHS 1979). Dissolved copper was found up to 0.38 mg/l and manganese recorded up to 31.0 mg/l. Bottom sediments were concentrated with insoluble metallic compounds, e.g. copper 49,680 mg/l dry weight.

TABLE 4

Selected physicochemical data for French Gulch, Yavapai County, Arizona (11 June 1980).

Parameter	French Gulch up- to downstream				Hassayampa River above confl. of French Gulch	State Standard
	A	B	C	D	E	
Elevation (m)	1315	1274	1212	1059	1050	
Stream-km above mouth	12.8	11.2	8.0	0.8	-	
Temperature (°C)	25.5	30.0	21.0	26.0	20.0	
pH	7.5	8.2	7.8	8.3	8.2	6.5 - 9.0
Conductance (mmho/cm)	3200	2600	1400	645	530	
Total Dissolved Solids (mg/1)	3521	2584	1294	461	433	
Total Hardness (mg/1 as $CaCO_3$)	2254	1850	850	282	249	
Total Alkalinity (mg/1)	252	190	208	206	184	
Calcium (mg/1)	550	450	225	80	70	
Magnesium (mg/1)	200	170	70	20	18	
Sulfate (mg/1)	2175	1575	650	98	69	
Total Copper (mg/1)	0.60	0.66	0.08	<0.05	<0.05	0.5
Dissolved Copper (mg/1)	0.38	0.30	0.08	<0.05	<0.05	0.05
Total Manganese (mg/1)	31.0	14.4	<0.05	<0.05	<0.05	10.0
Dissolved Manganese (mg/1)	27.0	12.8	<0.05	<0.05	<0.05	
Total Zinc (mg/1)	0.33	0.29	0.08	0.08	0.07	10.0
Dissolved Zinc (mg/1)	0.33	0.24	0.09	0.06	0.06	0.5
Total Iron (mg/1)	0.26	0.12	0.09	0.13	0.12	
Dissolved Iron (mg/1)	0.11	0.12	0.11	0.09	0.10	

Lewis (1978) reported on toxicity levels for native longfin dace (*Agosia chrysogaster*) from Pinto Creek, Gila County, Arizona. During replicated 96-hour static bioassays, the lethal copper concentration for 50% mortality (96-h LC50) of longfin dace was 0.86 mg/l. Zinc was most lethal (96-h LC50 = 0.79 mg/l) and copper-zinc combinations appeared more toxic than any metal ion alone (96-h LC50 = 0.21 mg/l copper mixed with 0.28 mg/l zinc). Manganese was least toxic of the metals tested (96-h LC50 = 130 mg/l) but increased in toxicity when mixed with copper salts (96-h LC50 = 64 mg/l manganese and 0.45 mg/l copper). Fish kills at or above these concentrations are not unusual. Lewis and Burraychak (1979) reported kills on two separate occasions in Pinto Creek which involved over 300,000 individual fish. Mortality in aquatic communities below copper mines has been reported from other Arizona watersheds, *i.e.* Lynx Creek (Follett and Wilson 1969), Mineral Creek (Rathbun 1975), and Boulder Creek (Kepner 1979).

Toxicity of effluents is typically reduced either by dilution or precipitation of metallic salts (Hynes 1960). The present situation is aggravated by alteration of the watershed to expose copper ore and the intermittency of flow. Toxicity to heavy metals in French Gulch is rarely diluted due to flow. Only through chemical neutralization in hard water were metal ions reduced to insoluble non-toxic forms (Tarzwell and Henderson 1960). Chemical parameters were found to decrease with distance downstream in the hard waters (1,309 ± 904 mg/l as $CaCO_3$) of French Gulch. Water quality on the lower reaches resumed near-normal values similar to background levels of the Hassayampa River (Table 4). Aquatic biota were absent at upstream stations, presumably due to the synergistic toxicity of copper-zinc mixtures. Both longfin dace and hydrophilid beetles (*Tropisternus*) were found over lower reaches (Station D) after metal ions had sufficiently precipitated out.

Macroinvertebrates

A total of 23 insect taxa within six orders was collected in Surber samples from the Bill Williams and Hassayampa drainages (Table 5). Dipterans were by far the most abundant organisms, both in actual numbers (68.4%) and in number of taxa (43.5%). Ephemeroptera and Trichoptera were the next most abundant orders (Fig. 6). Due to small sample size (N=15) and a limited sampling period, seasonal fluctuations in species compositon and abundance were not apparent.

Quantitative samples throughout both drainages were relatively depauperate in benthic fauna. Overall standing crop was limited, 90.8 ± 132.3 individuals/m^2 and 0.3917 ± 0.5673 g/m^2 (Table 6). Although there was a general paucity of taxa (4.1 ± 3.1 taxa/sample), the mean diversity value (3.44) was well within the range (2.6 - 4.0) considered to be indicative of "clean" water systems (Wilhm and Dorris 1968, Wilhm 1970).

Macroinvertebrate diversity and standing crops were delimited by a number of chemical/physical factors working either independently or in combination with each other. Aquatic insect populations were depressed for one or more of the following reasons: (1) seasonal variations in flow; (2) physiocochemical instability due to fluctuations either in flow or evapotranspiration; (3) scouring, abrasion, or siltation by predominantly fine sediments; and (4) lack of habitat diversity due to absence of heterogeneous substrate. The macroinvertebrate fauna reflected the instability of the aquatic habitats sampled and to some extent, the influx of catastrophic and behavioral drift. In particular, Surber samples detected the apparent homogeneity of Date Creek, Bill Williams River, and the lower reaches of the Hassayampa River. All three locations lacked riffles and contained bottoms which were continually swept clean by shifting sand particles. Surber samples at more than 27 stations failed to collect any aquatic invertebrates. Samples from similar habitat in other streams usually netted at least some members of the chironomid dipterans which typically can tolerate harsh environments coupled with low oxygen tensions and inundation by sediment (Bryce and Hobart 1972).

Macroinvertebrate collections from Kirkland Creek reflected the diversity of available habitat and bottom stability of that system. Kirkland Creek supported the highest overall density of aquatic invertebrates, both in standing crop (64.6 ± 97.9 individuals/m^2) and biomass (0.2580 ± 0.0860 g/m^2). However, mean diversity (1.51) was less than values obtained for the Hassayampa River and its tributaries (Table 6). The paucity of invertebrates (3 ± 2.6 taxa/sample) and the redundancy of black flies (*Simulium* sp.) were responsible for the low diversity value. *Simulium* comprised 78.8% of the Kirkland Creek macrobenthic collections, which included seven taxa.

The Hassayampa River drainage averaged 43.1 ± 36.1 individuals/m^2 and 0.1732± 0.2241 g/m^2 (Table 6). Habitat conditions were judged similar to those of Kirkland Creek except at downstream localities where siltation, fluctuating flow, and scouring by fine sediments were common. Aquatic

TABLE 5

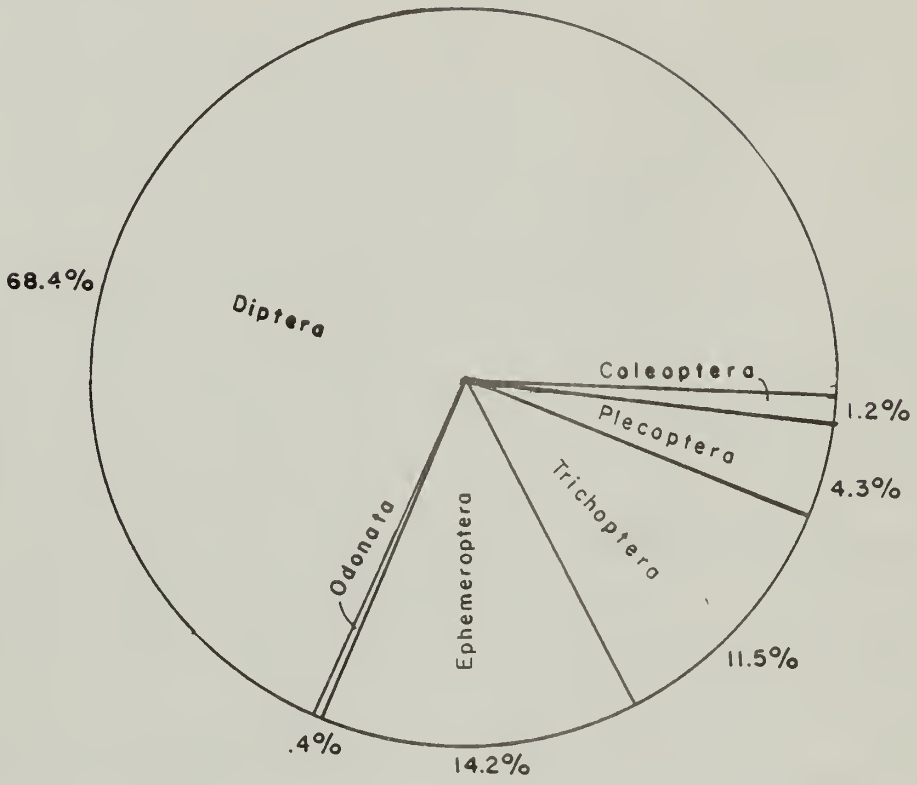
Taxonomic list of aquatic invertebrates collected in quantitative (Surber) samples from Bill Williams and Hassayampa River drainages, west-central Arizona, during March and April, 1980.

- Order Ephemeroptera
  - Family Tricorythidae
    - *Tricorythodes* Ulmer
    - *Leptohyphes* Eaton
  - Family Baetidae
    - *Baetis* Leach
    - *Baetis insignificans* McDunnough
    - *Pseudocloeon* Klapalek
- Order Odonata
  - Suborder Zygoptera
    - Family Coenagrionidae
      - *Argia* nr. *vivida* Hagen
- Order Plecoptera
  - Family Capnidae
    - indeterminate nymphs, probably *Capnia* Pictet or *Mesocapnia* Rauser
- Order Trichoptera
  - Family Hydropsychidae
    - *Cheumatopsyche* Wallengren
    - *Hydropsyche* Pictet
  - Family Sericostomatidae
    - *Gumaga* Tsuda
  - Family Helicopsychidae
    - *Helicopsyche* von Siebold
- Order Coleoptera
  - Family Haliplidae
    - *Peltodytes simplex* (Le Conte)
  - Family Dryopidae
    - *Helichus immsi* Hinton

Table 5. Continued.

Order Diptera
  Family Tipulidae
    Hexatoma Latreille
  Family Culicidae
    Culiseta incidens (Thomson)
  Family Simuliidae
    Simulium Latreille
  Family Chironomidae
   Subfamily Diamesinae
    Tribe Diamesini
   Subfamily Orthocladiinae
    Orthocladius van der Wulp or *Cricotopus* van der Wulp (indet. larvae)
    Smittia Holmgren
   Subfamily Chironominae
    Paratendipes Kieffer
  Family Ceratopogonidae
    Palpomyia Meigen group (in part, genera *Bezzia* and *Johannsenomyia*;
      larvae inseparable taxonomically)
  Family Stratiomyidae
    Euparyphus Gerstaecker
  Family Empididae
    indeterminate larva

Fig. 6. Macroinvertebrate composition of the Bill Williams and Hassayampa drainages, west-central Arizona, by number of individuals/taxon (above) and by number of taxa/order (below).



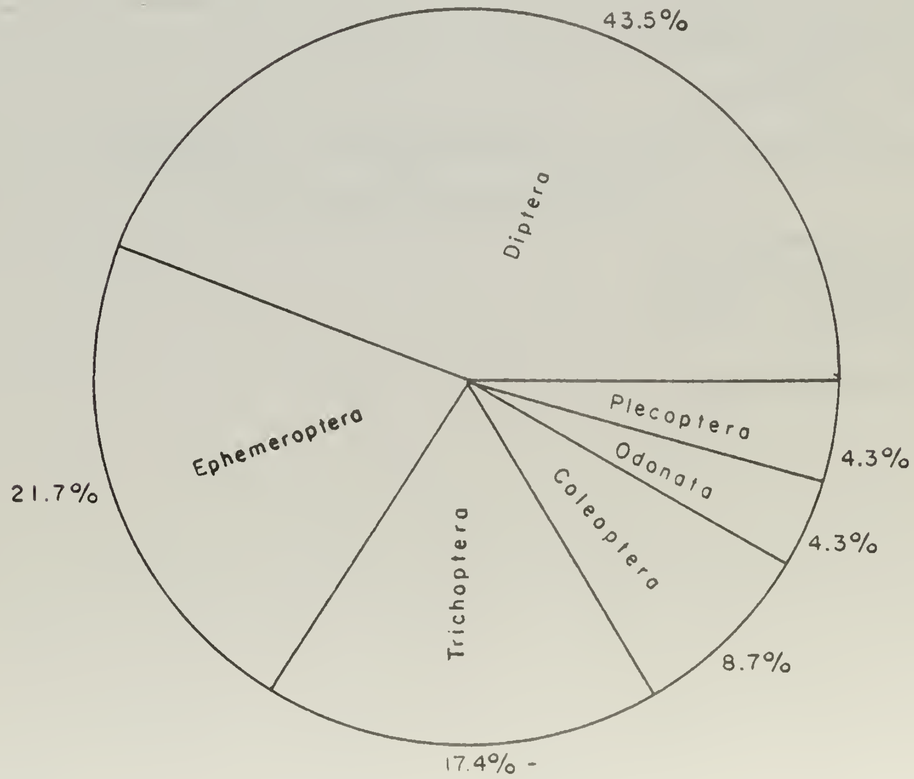


TABLE 6

Summary of quantitative data (± one standard deviation of the mean) and diversity ($\bar{d}$) for benthic invertebrates from the Bill Williams and Hassayampa drainages, March and April, 1980; ranges are in parentheses.

Locality	No. Samples	No. Taxa	Individuals/m^2	g/m^2	$\bar{d}$
Kirkland Creek	3	3±2.6 (1-6)	64.6±97.9 (5.4-177.6)	0.2580±0.0860 (0.2013-0.3569)	1.51
Hassayampa mainstream	5	2.6±1.8 (1-5)	39.8±42.5 (5.4-86.1)	0.1446±0.1875 (0.0393-0.4780)	2.44
Hassayampa tributaries	5	4.2±3.3 (1-9)	46.3±33.3 (5.4-96.9)	0.2017±0.2753 (0.0043-0.6836)	3.27
Hassayampa drainage	10	3.7±2.6 (1-9)	43.1±36.1 (5.4-96.9)	0.1732±0.2241 (0.0043-0.6836)	3.28
Total	15	4.1±3.1 (1-10)	90.8±132.3 (5.4-500.6)	0.3917±0.5673 (0.0043-1.9715)	3.44

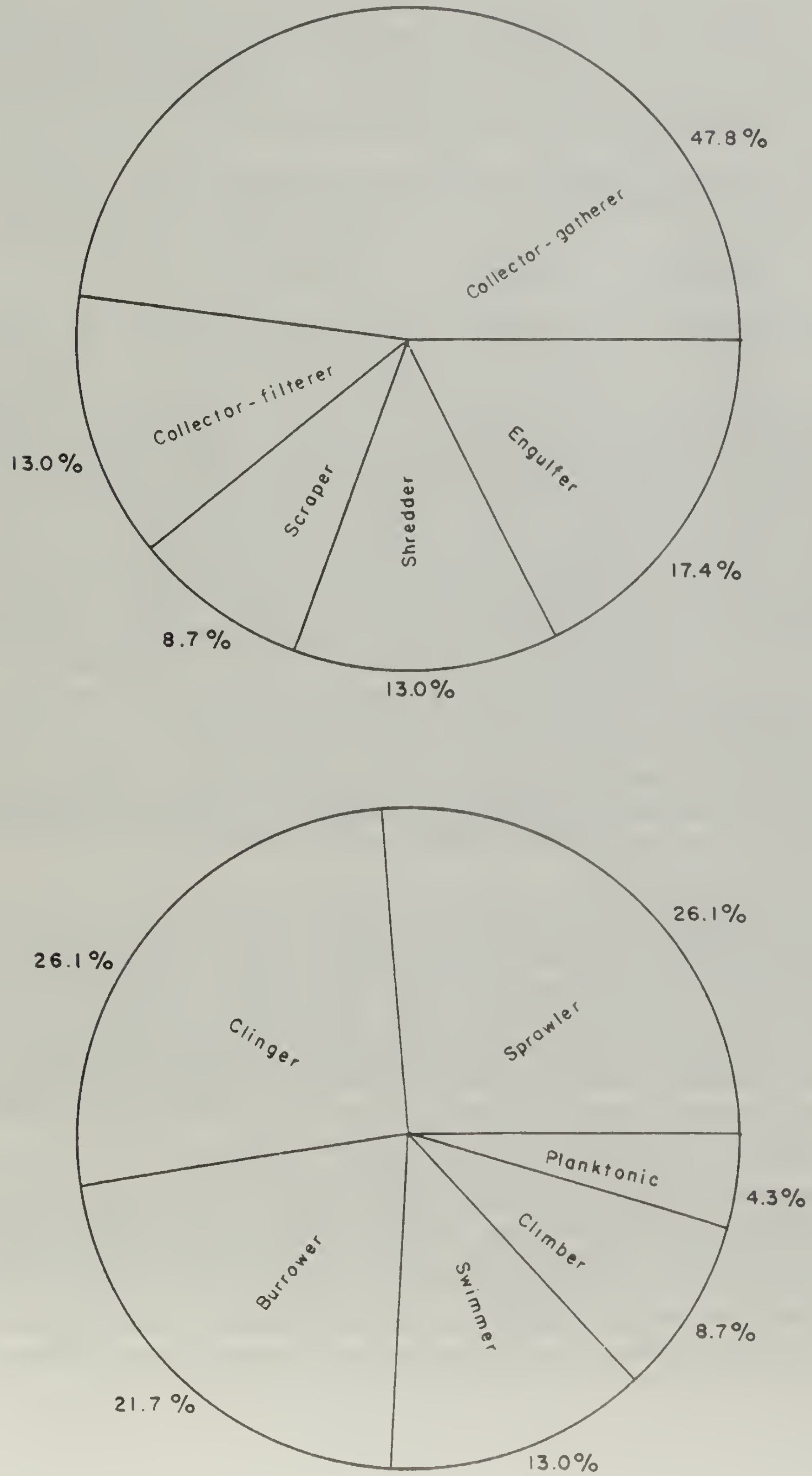
invertebrates similarly reflected changes in habitat with reduced diversity, numbers, and biomass and higher redundancy.

Tributaries to the Hassayampa were found to support aquatic insects at higher densities (46.3 ± 33.3 individuals/m^2 and 0.2017 ± 0.2753 g/m^2) than the Hassayampa mainstream (39.8 ± 42.5 individuals/m^2 and 0.1446 ± 0.1875 g/m^2). Diversity was also higher in the Hassayampa tributaries than mainstream stations (Table 6). Perennial tributaries are not subject to the magnitude nor frequency of flash flooding experienced in the mainstream and therefore present more physically stable habitats, and perhaps temporary refugia, to aquatic invertebrates. Only seven taxa were collected from mainstream stations as compared to 15 in the tributaries. Five of the seven mainstream taxa (Capnidae, *Hydropsyche*, *Orthocladius*, *Simulium* and Diamesini) were also common in the tributaries (Appendix 2).

Community structure of benthic macroinvertebrate populations is considered a reliable criterion to water quality. Gaufin and Tarzwell (1956), Gaufin (1973), and Cummins (1974) emphasize the use of specific assemblages or functional groups of organisms for environmental assessment rather than occurrence of indicator species. Hawkes (1979) discussed further the advantages and limitations of biological surveillance in monitoring water quality and presented examples of selected species exhibiting widely different degrees of tolerance to environmental perturbations. Others (Hynes 1959, 1960) consider benthic invertebrates better indicators of environmental quality or instability than physicochemical monitoring. Both traditionally tolerant and sensitive species were collected during the current study. Macroinvertebrate data at both the community and specific level was found consistent with water quality in documenting habitat condition. In certain instances where stream bottoms were unstabilized, diversity indices fell below 1.0, the value normally associated with either physically stressed or chemically polluted environments (Wilhm 1970). Composite diversity values for each drainage were above 1.5, indicating conditions ranging from moderate to no stress. The most diverse and numerically abundant insect populations occurred in headwater areas. The macroinvertebrate fauna at downstream localities was indicative of physically-stressed communities which favored osmotically and thermally tolerant taxa. Lower reaches were dominated by salt-tolerant chironomid dipterans, hydropsychid caddisflies, and hydrophilid beetles. The Baetidae appeared to be the most tolerant ephemeropteran family and Plecoptera were conspicuously absent at high salinities on the lower stations.

The apparent lack of macroinvertebrate diversity and abundance on downstream stations was also attributable to the lack of diversity in aquatic habitat. To further illustrate conditions of the study area, the macroinvertebrate fauna was divided into functional ecological groups following Cummins (1974) and Merritt and Cummins (1978). The predominance of dipteran and ephemeropteran taxa accounted for the large collector-gatherer category (Fig. 7). Collector-filterers, *e.g.* *Hydropsyche* and *Simulium*, were notably less abundant due to scouring and sediment deposition from suspended solids and from lack of suitable substrate for attachment sites. Aquatic insects were almost evenly divided between three habitat categories, *i.e.* sprawler, clinger, and burrower (Fig. 7). Other categories were less representative of the prevailing physicochemical instability and erosive features of the drainages.

Fig. 7. Functional group classification of macroinvertebrates of the Bill Williams and Hassayampa drainages, west-central Arizona, by trophic relation (above) and by habit (below). Modified from Cummins (1974) and Merritt and Cummins (1978).



Ichthyofauna

Accounts of Species

More than 8,100 fish were collected during the current study. Field collections, combined with available museum records, indicate occurrence of 20 species and one hybrid combination representing seven families (Appendix 3). Four of the species are native to the Bill Williams and Hassayampa drainages and none are protected under federal or state listings for threatened, endangered, and sensitive species.

Native Fishes. Native fishes of the study area are widely distributed throughout Arizona within the Gila and Colorado River basins. Native fauna consisted of cyprinid and catostomid species adapted to the widely fluctuating physicochemical conditions of low-desert streams.

Agosia chrysogaster Girard, longfin dace: Longfin dace is one of the most ubiquitous southwestern minnows (Minckley and Barber 1971). *Agosia* was the predominant species in all streams sampled except the Bill Williams River, where it presumably has been displaced by red shiner (*Notropis lutrensis*). This species was typically most common in laminar runs with sandy bottoms where cover was provided by overhanging vegetation, flood debris, or undercut banks. Adult populations are rarely reduced as the result of flash flooding (Minckley 1973) and are tolerant of elevated summer temperatures (Lowe *et al*. 1967, Minckley 1973). Spawning is protracted in saucer-shaped nests in the sand throughout much of the year. During the current study, longfin dace spawned in shallow (6.3 ± 2.5 cm), sand-bottomed backwaters. Nests varied from 1 to 28/m^2 and averaged 22 ± 5.8 nests/m^2. Males in breeding condition were collected as early as February with nuptial tubercles present on the head, operculum, and all fins except the caudal.

Agosia are diurnal feeders and opportunistic omnivores. In Aravaipa Creek, Arizona, major food items in addition to algae and detritus included aquatic insects, primarily baetid mayfly naiads and chironomid dipterans associated with drift (Schreiber 1978).

Gila robusta robusta Baird and Girard, roundtail chub: Roundtail chub was only collected from the Bill Williams drainage. They were numerous near the confluence of Kirkland and Sycamore creeks and totally absent from the Bill Williams River below Alamo Dam, where they once occurred prior to impoundment. Large adults tended to congregate in suitable pools and smaller juveniles over riffles. They are opportunistic omnivores and feed on terrestrial and aquatic invertebrates, algae, and on occasion, other fishes (Vanicek and Kramer 1969, Neve 1976, Schreiber 1978).

Catostomus insignis Baird and Girard, Gila sucker: Gila sucker like roundtail chub, was only present in the Bill Williams drainage. They were typically collected from deep, quiet pools or over laminar runs with overhanging vegetation. *C. insignis* feed on aquatic and terrestrial drift along stream margins and pool bottoms, and infrequently visit riffle areas. Schreiber (1978) reported a generalized diet of several food items, principally baetid ephemeropteran naiads and chironomid dipterans, in Aravaipa Creek.

Pantosteus clarki (Baird and Girard), Gila mountain-sucker: *P. clarki* was widely distributed in both drainages with the exception of the Bill Williams River below Alamo Dam and Date Creek. They were most frequently collected in headwater areas where shallow riffles with rocky, cobble bottoms were prevalent. Large adults were occasionally observed in pools where individuals of the previous sucker tended to congregate. Gila mountain-suckers feed primarily on filamentous green algae, *e.g.* *Mougeotia*, *Spirogyra*, *Cladophora*, and *Oedogonium*, and attached diatoms which they scrape from cobble riffles (Schreiber 1978). Hybrids of *P. clarki* and *C. insignis* have been reported at low frequencies in other watersheds (Hubbs *et al.* 1943, Miller and Lowe 1964, Barber and Minckley 1966, Smith 1966, Kepner 1979), but were not collected in the current study.

Introduced Fishes. The introduced fishes included 16 species and one hybrid, 15 of which occur in Alamo Lake. The introduced fauna included cyprinids, ictalurids, centrarchids and one poeciliid.

Notropis lutrensis (Baird and Girard), red shiner: Red shiners have been introduced largely as a result of bait transfers from east of the Rocky Mountains. Red shiner was first introduced as a forage fish into the lower Colorado River in 1955 (Miller 1952, Hubbs 1954, USFW 1980) from where they rapidly dispersed to other perennial tributaries. They are omnivorous and occupy similar habitat as *Agosia chrysogaster*. They were present in large numbers in runs and backwater areas of the Bill Williams River. Spawning is from March through June in laminar runs over gravel substrate, where ova are indiscriminately broadcast over the bottom (Minckley 1972).

Red shiners exhibit wide physicochemical tolerances and are therefore capable of exploiting habitats unfavorable to other more specialized species (Matthews and Hill 1977, 1979). This species has been implicated in the decline and extirpation of native minnows throughout the state (Minckley and Deacon 1968, Minckley and Carufel 1967, Minckley 1973).

Cyprinus carpio Linnaeus, carp: Carp were taken from backwaters of the Bill Williams River where they achieve relatively large sizes (>465 mm TL). Occasionally smaller adults and juveniles were collected from beneath undercut banks of the main channel. Both adults and juveniles were present in limited numbers, even in backwaters where they feed over sand/silt bottoms for benthic invertebrates, *e.g.* chironomid dipterans, and detritus. Their occurrence presumably resulted from introductions in the lower Colorado River during the 1880s (USFW 1980).

Spawning activities are reported to begin in April and extend through July for specimens taken from the Colorado River (Minckley 1979). Carp may spawn as early as February or March in backwaters of the Bill Williams River which are not circulated with cooler water of the mainstream. Typically, they initiate spawning when water temperatures consistently reach 15.5 °C (Burns 1966b).

Pimephales promelas Rafinesque, fathead minnow: Fathead minnows were rarely collected during the present study. They were taken from small perennial tributaries of the Hassayampa River and at one station on the mainstream. Their presence presumably results from their popularity as a legal bait minnow in Arizona.

Males are larger than females but rarely exceed over 75 mm in length (Lewis 1976). Foods taken by fathead largely consist of detritus and algae.

Fathead minnows are reportedly intolerant of other cyprinid species (Hubbs and Cooper 1936, Starret 1950). They were extremely abundant in isolated cattle tanks in Peeples Valley, but infrequently taken in Hassayampa tributaries when in the presence of native longfin dace.

Ictalurus melas (Rafinesque), black bullhead: Black bullheads were common in sand-bottomed pools along Bland Creek. They were infrequently collected from undercut banks along runs in Kirkland Creek and the Santa Maria River. Black bullhead are omnivorous in their food habits and have been reported to spawn in Arizona waters from March through June (Minckley 1979).

Chaenobryttus cyanellus (Rafinesque), green sunfish: Green sunfish are widely distributed in Arizona and common in the Bill Williams drainage. Adults were collected from backwaters and pools with limited cover and sluggish currents. Juveniles were common near undercut banks with overhanging vegetation and swifter currents. Both young and mature fish feed on aquatic and terrestrial insects, small crustaceans and mollusks, and other fish, including their own kind.

Gambusia affinis affinis (Baird and Girard), mosquitofish: Mosquitofish were abundant in shallow, quiet backwater areas of the Bill Williams River. They were less common along stream margins, but could be found where vegetative cover was present over the main channel. Their introduction results from their worldwide reputation as vector control agents, although they are also a legal bait fish in Arizona. *Gambusia* were first collected in Arizona in 1926 from the Gila River near its confluence with the Colorado River. (Miller and Lowe 1964). Due to the aggressive colonizing nature of this species, mosquitofish have successfully invaded suitable habitat in the Bill Williams River and have established large populations in the backwaters.

Mosquitofish are sexually dimorphic, with males and females differing markedly in their external physical appearance and size. Males are much smaller than females and are equipped with an elongated anal fin modified into a copulatory organ, the gonopodium. Females are internally fertilized and bear their young alive. They are capable of bearing repeated broods, up to five, from a single insemination. (Krumholz 1948).

Mosquitofish are opportunistic omnivores, usually taking their prey close to the water surface. They feed on mixed diets of aquatic and terrestrial insects, algae and detritus, and fish, including their own young.

Gambusia have been implicated in the decline and extirpation of a number of southwestern native fishes, particularly the endangered Gila topminnow

(*Poeciliopsis occidentalis*), through predation and competitive interaction (Evermann and Clark 1931, Miller 1961, Miller and Lowe 1964, Minckley and Deacon 1968, Minckley *et al*. 1977). Other cases of decline and local extinction of native fishes throughout the world have been documented by Myers (1965) as resulting from *Gambusia* introductions.

Alamo Lake. Alamo Dam is a prominent hydrologic feature within the Bill Williams drainage. The entire icthyofauna of Alamo Lake has been introduced to establish a warmwater sport fishery. This includes 15 species and one hybrid (Appendix 3). Initially, it was stocked with largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), redear sunfish (*Lepomis microlophus*), and yellow bullhead (*Ictalurus natalis*) by the Arizona Game and Fish Department in March of 1968. Stocking of flathead catfish (*Pilodictis olivaris*), shellcrackers (*Lepomis microlophus* x *Chaenobryttus cyanellus*), and bullfrogs (*Rana catesbeiana*) followed the initial stocking. Other species of fish now are established in Alamo Lake and are usually present in fishermens' creel. Origin of their introduction is unknown, but probably occurred as the result of either bait transfer and release or invasion of the upper basin prior to impoundment in 1968.

Bluegill (*Lepomis macrochirus*) have supplanted redear sunfish and were main forage fish for the productive bass fishery until threadfin shad (*Dorosoma petenense*) were recently introduced. Threadfin shad school in open surface waters of many of the Arizona reservoirs. Shad have typically been introduced as forage species for piscivorous game fishes, but now may actually compete with juvenile centrarchids for planktonic foods, *e.g.* zooplankton, phytoplankton, and detritus (Gerdes and McConnell 1963, McConnell and Gerdes 1964, Burns 1966a, Moyle 1976).

Relative Abundance

Ten species of fish were collected during electrofishing operations (Table 7). Longfin dace clearly dominated all collections except those of the Bill Williams River, where it was never taken. Overall, it made up 77.2% of the total collections and comprised 100% of the total fauna of Date Creek.

Red shiner was second in relative abundance (11.1%), although it was restricted to a single watershed, the Bill Williams River. The fact that no sport fishery exists in the other streams sampled, has precluded its introduction and establishment as a bait minnow.

Gila mountain-sucker was found over riffles of Kirkland Creek and the Hassayampa drainage where it accounted for 1.3 and 12.2% of the fauna, respectively.

Mosquitofish were abundant in backwaters along the Bill Williams River and were fourth in overall abundance (4.1%). All other species collectively made up less than 1.0% of the total catch.

TABLE 7

Relative abundance of fishes in the Bill Williams and Hassayampa River drainages, February through May, 1980. Data are shown as percentage of total catch and parentheses indicate total number collected.

Taxa	Date Creek	Kirkland Creek	Bill Williams River	Hassayampa River and Tributaries	Total
Longfin dace	100(858)	97.7(1209)		87.6(3419)	77.2(5486)
Roundtail chub		0.2 (3)			Tr.(3)[1/]
Fathead minnow				0.1 (5)	0.1(5)
Red shiner			71(790)		11.1(790)
Carp			0.9 (10)		0.1 (10)
Gila mountain-sucker		1.3(16)		12.2(477)	6.9(493)
Gila sucker		0.1 (1)			Tr. (1)
Black bullhead		0.2(2)			Tr. (2)
Green sunfish		0.5(6)	1.7(19)		0.4(25)
Mosquitofish			26.4(294)		4.1(294)
Total Fish Collected	858	1237	1113	3901	7109
Percentage Native	100	99.4	0	99.9	84.2

[1/] Tr. = less than 0.05%

Only 15.8% of all fishes taken were introduced forms. Non-native fishes were almost entirely restricted to the Bill Williams River. They have entered that system *via* introductions to the Colorado River during the mid-1950s or earlier. All other streams were dominated by native fishes, particularly longfin dace. Native fishes of Kirkland Creek, Hassayampa River and tributaries, and Date Creek comprised 99.4, 99.9, and 100% of the fauna, respectively (Table 7).

The Bill Williams and Hassayampa drainages supported relatively few fish taxa at low standing crops, 1.7 ± 1.7 fish/m^2 and 6.0 ± 7.1 g/m^2 (Table 8). Minckley (1979) reported similar standing crops ($\bar{1}.69$ fish /m^2) in seining collections from the lower Colorado River mainstream.

Kirkland Creek supported the highest overall density of fish (3.3 ± 3 fish/m^2), perhaps in response to the higher benthic prey-base (see Macroinvertebrate Section). Fish densities for the Hassayampa mainstream and tributaries reflected similar trends as their macroinvertebrate populations. Fish were present in higher standing crops (2.0 ± 1.1 fish/m^2) and biomass (10 ± 6.8 g/m^2) in perennial tributaries to the Hassayampa than in the mainstream itself (1.3 ± 0.8 fish/m^2 and 5.8 ± 5.8 g/m^2).

Fish numbers in Date Creek equaled those in the Hassayampa mainstream (1.3 ± 0.8 fish/m^2) and almost equaled the total number present within the Hassayampa drainage, mainstream and tributaries included (1.4 ± 0.9 fish/m^2). The absence of large-bodied Gila mountain-sucker in Date Creek produced lower biomass, 1.4 ± 0.9 g/m^2, than the Hassayampa River or its tributaries combined (Table 8).

Population estimates for the Bill Williams River were the lowest of all perennial streams sampled, 0.2 ± 0.1 fish/m^2 and 0.9 ± 0.5 g/m^2. Perhaps a small sample size (N=3) underestimated fish densities. Fish populations were typically clustered in distribution, depending on available habitats. Most were concentrated in connected backwaters to the mainstream which act as periodic refugia against flooding and drought. Low densities may therefore accurately reflect the general lack of habitat diversity in the Bill Williams mainstream.

Habitat Partitioning

Habitat relationships among fishes of the Bill Williams and Hassayampa drainages were evaluated around the various physical parameters that could be quantified in the field. Fish data were grouped and quantified at the habitat level and tested for significance where possible (Table 9).

Absolute densities determined from removal sampling indicated backwater habitats supported the highest number of fish (6.9 ± 13.6 fish/m^2) and riffles the least (0.6 ± 0.5 fish/m^2). This is attributed to the abundance of mosquitofish in backwaters of the Bill Williams River and particularly to the large schools of longfin dace which spawned in the backwaters of Kirkland Creek and the Hassayampa River.

TABLE 8

Summary of quantitative data (± one standard deviation) for total fishes from the Bill Williams and Hassayampa drainages, February through May, 1980; ranges are in parentheses.

Locality	N	Fish/m^2	g/m^2	Total Taxa
Date Creek	6	1.3±0.8 (0.4-2.6)	1.4±0.9 (0.6-3.1)	1.0±0
Kirkland Creek	7	3.3±3 (0.2-8.0)	9.8±11.1 (0.8-32.8)	1.6±0.5 (1-2)
Bill Williams River	3	0.2±0.1 (0.1-0.3)	0.9±0.5 (0.5-1.5)	2+1 (1-3)
Hassayampa River (mainstream)	16	1.3±0.8 (0.2-3.2)	5.8±5.8 (0.4-23.2)	1.6±0.5 (1-2)
Hassayampa tributaries	5	2.0±1.1 (0.8-3.8)	10±6.8 (4.2-21.6)	2.2±0.4 (2-3)
Hassayampa drainage	21	1.4±0.9 (0.2-3.8)	6.8±6.1 (0.4-23.2)	1.8±0.5 (1-3)
Total	37	1.7±1.7 (0.1-8.0)	6.0±7.1 (0.4-32.8)	1.6±0.6 (1-3)

TABLE 9

Quantitative data (mean fish/m^2 ± one standard deviation) for total fishes in different habitat types of the Bill Williams and Hassayampa drainages, February through May, 1980.

	Run	Riffle	Pool	Backwater	Total
All Fish	1.3±1.9 N=44	0.6±0.5 N=44	1.4±2.5 N=7	6.9±13.6 N=8	1.4±4.2 N=103
All Native	1.5±1.7 N=34	0.6±0.5 N=40	2.5±3.9 N=3	21.0±26.9 N=2	1.6±4.6 N=79
All Introduced	0.9±2.6 N=10	0.1±0.2 N=4	0.6±0.7 N=4	2.2±2.7 N=6	1.0±2.2 N=24

Although backwaters supported the highest densities of fish, the only significant difference between habitat types at the $p=0.95$ level occurred between riffles and runs. There were no significant differences however, when natives were compared against natives (1.5 ± 1.7 fish/m^2 of run *vs.* 0.6 ± 0.5 fish/m^2 of riffle) or non-natives against non-natives (0.9 ± 2.6 fish/m^2 of run *vs.* 0.1 ± 0.2 fish/m^2 of riffle). Native fish total density (1.6 ± 4.6 fish/m^2) *vs.* non-native (1.0 ± 2.2 fish/m^2) was significantly different at the $p<0.99$ level. When native fish were further compared to introduced species, significant differences were detected for runs ($p<0.99$) and riffles ($p<0.95$). In both cases, more natives were present in each habitat type than introduced forms (Table 9). Native and introduced densities were not significantly different for pools and backwaters.

Fish data were further quantified at the species level (Table 10). Mosquitofish and longfin dace primarily utilized shallow backwaters. Carp were also collected in backwater situations on the Bill Williams River. Red shiners were taken in backwaters, but were most abundant in laminar currents over sand-bottomed runs. Gila mountain-sucker preferred swifter currents over riffles and was found in association with larger substrate types, *e.g.* cobble/rubble. Black bullhead and green sunfish were most often taken in more lentic situations of little or no current and occurred in areas where cover was provided from either cut banks and/or overhanging riparian vegetation. They were most abundant in soft-bottomed pools less than a meter in depth.

Data were sufficient for only two species, longfin dace and green sunfish, to test for habitat preference at the species level. There were no significant combinations in almost all cases tested. Only in one instance, for longfin dace (21.0 fish/m^2 of backwater *vs.* 0.81 fish/m^2 of riffle), did fish densities per given habitat type prove significant at the $p=0.95$ level.

Distribution of longfin dace, Gila mountain-sucker, and green sunfish was further tested where cumulative data, *i.e.* stream gradient, mean depth, width, elevation, stream velocity, discharge, and percent cover, were available. Kolmogorov-Smirnov tests failed to identify any physical parameter over which longfin dace were selectively distributed. Gila mountain-suckers were more specific in their habitat preferences. *Pantosteus clarki* was found significantly distributed ($p=0.95$) over depth, width, velocity, gradient, and percent cover. At the $p=0.90$ level they were selective over elevation. Means and 95% confidence intervals for each parameter are given in Table 11. Green sunfish populations were significantly distributed over depth. They were generally found in shallow pools which did not exceed more than 0.5 m in depth (Table 11).

The Mann-Whitney U-test was used to test fish distribution over discontinuous data, *i.e.* stream substrate. Substrate was grouped into two size categories, small (sand and gravel, 0.006 - 6.4 cm diameter) and large (cobble and rubble, 6.41 - 30.5 cm). Longfin dace were nonselective towards substrate size although nests were constructed almost entirely over sand/gravel bottoms in backwaters. Gila mountain-sucker was significantly distributed ($p=0.90$) over shallow cobble/rubble riffles where they feed on perilithic algae.

TABLE 10

Summary of quantitative fish data (mean fish/m^2 ± one standard deviation) by habitat type for the Bill Williams and Hassayampa drainages, February through May, 1980.

Taxa	Riffle	Run	Pool	Backwater
Longfin dace	0.81±0.59 N=23	1.7±1.77 N=29	2.51±3.87 N=3	21±26.93 N=2
Carp	-	-	-	0.17 N=1
Red shiner	0.48 N=1	2.15±4.04 N=4	-	1.24±0.08 N=2
Fathead minnow	-	0.01±0.01 N=2	-	-
Gila mountain-sucker	0.32±0.32 N=17	0.17±0.24 N=5	-	-
Black bullhead	0.04 N=1	-	0.24±0.04 N=2	-
Green sunfish	0.03±0.02 N=2	0.08±0.06 N=3	1.03±0.89 N=2	0.06 N=1
Mosquitofish	-	0.03 N=1	-	5.23±2.92 N=2

TABLE 11

Means and 95 percent confidence intervals for each parameter over which Gila mountain-sucker (*Pantosteus clarki*) and green sunfish (*Chaenobryttus cyanellus*) were significantly distributed.

Parameter	Gila mountain-sucker N=28 stations	Green sunfish N=10 stations
Mean depth (m)	0.22±0.03	0.27±0.10
Width (m)	6.65±1.73	
Mean velocity (m/sec)	0.88±0.11	
Stream gradient (°)	1.28±0.16	
Percent cover	11.55±9.45	
Elevation (m)	961.43±51.40	

SUMMARY

The Bill Williams and Hassayampa drainages have escaped major water resource development and flow relatively undisturbed by human activity. Discharge is highly variable in both drainages and ranges from flash flooding in the winter to intermittent flows in early summer and fall. Chemical and physical water quality was generally within acceptable state (ADHS 1979) and federal (USEPA 1976) standards for surface waters. The exception being French Gulch below the Zonia Copper Mine and perhaps Planet Wash below the abandoned Planet Mine. Dissolved oxygen values were generally high, and pH consistently alkaline. Major plant nutrients, $PO_4 - P$ and $NO_3 - N$, occurred in variable concentrations and appear to be controlled by edaphic and *in situ* biological factors. They were quickly assimilated by stream autotrophs in the upper reaches and fell to negligible levels downstream. High $PO_4 - P$ levels are presumed to be edaphically derived from Tertiary basalts present in the headwaters. Although livestock grazing is a major land use over both drainages and can affect $PO_4 - P$ and $NO_3 - N$ levels, it is generally considered diffuse, *i.e.* a non-point source (Vollenweider 1970). Of nutrients, $PO_4 - P$ was typically higher than $NO_3 - N$ levels. Nitrate-nitrogen availability rather than phosphate-phosphorus, may be the critical factor limiting primary productivity in desert streams.

Quantitative sampling over both drainages indicated a general paucity of aquatic invertebrates. Surber samples were largely dominated by chironomid dipterans. Fluctuations in flow and physicochemical stability in addition to scouring, abrasion, inundation and lack of habitat diversity appear to be major factors controlling macroinvertebrate distribution and abundance. Although a depauperate fauna appeared to be typical of the study area, diversity indices were within ranges indicative of clean water systems.

Field collections combined with museum records indicate at least 20 species of fish occur over both drainages. Of these, only four were native to the area, yet collectively accounted for more than 84% of the total collections. Longfin dace clearly dominated all collections and were indicative of the sandy runs present over much of the area. Overall, fish were found in standing crops similar to those of other low-desert streams. Backwaters supported the highest densities of both native and introduced fish. Riffles were least productive, but were important habitat for some species of fish, *i.e.* Gila mountain-sucker. Longfin dace had very broad habitat requirements and were found in every habitat type sampled. In contrast, Gila mountain-sucker were very specific in their habitat selection and were typically found over swift, shallow, cobble/rubble riffles with gradients over 1°.

Kirkland Creek was the most productive system sampled, at least in terms of biomass and standing crop for both aquatic invertebrates and fish. This is attributed to at least two factors: stability or perhaps diversity of the system, and availability of plant nutrients. Stream bottoms in Kirkland Creek were dominated by large substrate types which presented permanent sites of attachment for the sedentary aquatic insects and escaped the scouring and inundation typical of fine sediments. Kirkland Creek had the highest concentrations of dissolved mineral salts and orthophosphates of any stream sampled. Nitrate-nitrogen was the only plant nutrient not available in excess and may be the factor limiting further primary production of that system. Nitrate-nitrogen levels in Kirkland Creek were the lowest recorded throughout the study and were rapidly depleted by stream autotrophs in the headwaters.

Fish populations in Kirkland Creek reflect the diversity of available habitats and the high standing crops of aquatic invertebrates. Kirkland Creek supported the greatest number of fish species at the highest standing crops of all streams quantitatively sampled.

RECOMMENDATIONS

In accordance with the Federal Land Policy and Management Act of 1976 and under the multiple-use concept adhered to by the U.S. Bureau of Land Management, aquatic ecosystems and their management are considered a natural resource of public lands.

Management of aquatic habitat by appropriate state and federal land agencies should insure the environmental quality and stability of the ecosystem where possible. The following management recommendations are based on the current limnologic study and are proposed to enhance and maintain aquatic resources on the Harcuvar, Vulture, and Skull Valley planning units.

1. Limit or eliminate grazing by livestock in riparian areas to insure bank stability and stream cover through successful regeneration and growth of streamside vegetation.

   Overgrazing can alter and degrade the quality of a watershed in a variety of ways, which collectively reduce diversity and density of the benthic community in streams (Cordone and Kelley 1961) and result in the decline of fish productivity (Marcuson 1977).

   Removal of riparian vegetation and prevention of its regeneration by livestock grazing or trampling has been implicated in increased water temperatures, increased runoff and erosion, and reduced cover for fisheries (Alderfer and Robinson 1947, Packer 1953, Boussu 1954, Sharp *et al*. 1964, Lusby 1970, Smiens 1975, Behnke and Raleigh 1978). Trampling alone may result in bank caving and sloughing, soil compaction, reduced soil infiltration, accelerated sedimentation, and reduced establishment or survival of tree seedlings (Armour 1977, Meehan and Platts 1978). Excessive eutrophication of aquatic ecosystems by livestock defecation results in pollution and bacterial contamination (Robbins *et al*. 1972). Reduced oxygen tensions and increased ammonia concentrations are indicative of organic loading by livestock (Scalf *et al*. 1970).

   Riparian corridors on western ranges can no longer tolerate the abuse of improper management of domestic livestock and impaired conditions should be met with alternative management plans. Reduction in the number of cattle or building exclosures to keep cattle from riparian vegetation may not be the immediate solution to the problem of overutilization. Cattle tend to congregate along stream bottoms and remaining livestock would continue to graze the streamside vegetation during dry periods of the year under the first alternative. Secondly, fences across desert streams are generally short-lived structures and are rarely immune to flash flooding during periods of heavy winter precipitation. Grazing should be eliminated from riparian communities and deferred to upland terraces to avoid further losses of riparian habitat and degradation of the aquatic ecosystem.

2. Maintain instream flows to provide for needs of aquatic life, wildlife, and riparian vegetation. Discourage diversions, impoundments, or further withdrawals of groundwater. File for water rights of surface waters on public lands.
   Any changes in flow regime are likely to result in altered physicochemical water quality and replacement of native fishes with lentic-adapted introduced forms. Reduced flows typically elevate water temperatures and increase conductivity and total dissolved solids from lack of dilution by surface waters. Waters may become intolerable for some forms of aquatic biota and unsuitable for agricultural purposes. Regulated flows are likely to damp out the seasonality of flash flooding and in the case of severe flow reduction, jeopardize riparian woodlands due to drawdown of the water table.

   Flash flooding is a natural phenomenon which maintains the uniqueness of low-desert streams. Heavy winter discharges uproot saltcedar seedlings and prevent their invasion and establishment of disclimax communities. Sporadic flash flooding is also known to maintain native fish populations in Arizona watersheds, *e.g.* Burro Creek (Kepner 1979) and Bonita and Eagle creeks (Minckley and Sommerfeld 1979), by displacing introduced species downstream and decimating their populations. Perhaps the impoundment of the Bill Williams River and regulation of its flow has allowed the total extirpation of native fish below Alamo Dam and the displacement of native riparian species with saltcedar.

   Certificate of Water Rights are the only accepted legal basis to appropriate water in Arizona. Wherever feasible, BLM hydrologists should file for water rights and a priority date obtained from the Arizona Water Commission to legally maintain and reserve perennial waters for use by wildlife, aquatics, riparian vegetation, livestock, recreation, *etc*. This would serve to protect present water uses and provide for future needs as they arise.

3. Survey natural springs for endemic aquatic invertebrates, particularly gastropods, prior to development as range improvements for domestic livestock or as water catchments for wildlife.

   Generally, past water developments have been undertaken with little regard toward aquatic invertebrate populations. In many cases, rare forms have been eliminated as the result of range and wildlife improvements. Due to the high degree of endemism typical of closed desert basins, *e.g.* Death Valley (California), Ash Meadows (Nevada), and Cuatro Cienegas (Coahuila, Mexico), many forms are extremely rare and are currently being investigated for potential listing as threatened or endangered species with the U.S. Fish and Wildlife Service, particularly in the states of Texas, Oklahoma, New Mexico, and Arizona (Landye 1973, 1980a, 1980b). In most cases, endemic aquatic invertebrates are compatible with water developments providing their populations have been identified prior to construction and their biological requirements provided for.

4. Report violation of state and federal water quality standards in French Gulch to the appropriate government agencies and recommend enforcement action. Arizona state surface water quality standards were exceeded for copper and manganese in flows originating below the Zonia Copper Mine in French Gulch. Waters below the mine were highly mineralized and contained levels of sulfate which would impair its suitability for livestock watering.
   Sediments within the stream channel were concentrated with insoluble metallic compounds, particularly copper. Sediment samples were in violation of state hazardous waste regulations for chromium, cadmium, lead, and selenium. Although surface waters were in violation for manganese, toxicity to copper-zinc mixtures in the upper reaches appears to be the factor limiting its suitability to sustain aquatic biota.

   As a management agency, BLM is concerned with the water quality of French Gulch on public lands as it relates to aquatic and wildlife resources and its suitability for livestock watering and human consumption. The McAlester Fuel Company does not possess a permit to discharge acid mine drainage into French Gulch and it is our recommendation that a cease discharge order be issued to the Zonia mining operation from the ADHS (Phoenix) and/or the USEPA (Region 9, San Francisco).

5. Maintain both drainages as native non-game fisheries and discourage introduction of non-native species for bait and sport fishery purposes or vector and weed control.

   Although native fishes thrive in almost all areas of both drainages, introduced forms suffer problems associated with shifting substrates and scouring from flooding, elevated summer temperatures, seasonal intermittency of flow, and low benthic prey-base. The majority of the desert streams surveyed do not satisfy game fish requirements. The two sport fish present over much of the area, green sunfish and black bullhead, reportedly have a history of stunting under unsatisfactory conditions (Miller and Alcorn 1946) and generally are too small to be desirable as game fish. Therefore, any introductions of game fish are anticipated as being burdened with problems of limited access and minimal harvest and would scarcely attract the interests of the fishing public. Other problems associated with extirpation and replacement of native fish populations by introduced species (Miller 1961, Minckley and Deacon 1968, LaBounty and Minckley 1972), could easily be avoided by curtailing introductions of non-native species, particularly red shiner and mosquitofish.

   Alamo Lake appears to be the best alternative to expanding the sport fishery throughout the planning area. It presently satisfies recreation needs of the public and supports what is considered the best warmwater fishery in the state for centrarchids and ictalurids alike.

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APPENDIX 1. Locations and elevations of inventory stations.

North Fork Date Creek

Stat. 1	Ariz., Yavapai Co., T. 11 N., R. 6 ., SW1/4, Sec. 29, elev. 3220'

South Fork Date Creek

Stat. 2	Ariz., Yavapai Co., T. 11 N., R. 6 W., NW1/4, Sec. 32, elev. 3220'

Date Creek

Stat. 3	Ariz., Yavapai Co., T. 11 N., R. 6 W., NW1/4, Sec. 32, elev. 3210' below confl. of North and South Forks
Stat. 4	Ariz., Yavapai Co., T. 11 N., R. 6 W., SE1/4, Sec. 30, elev. 3180' above confl. of Cottonwood Creek
Stat. 5	Ariz., Yavapai Co., T. 11 N., R. 6 W., SW1/4, Sec. 30, elev. 3150'
Stat. 6	Ariz., Yavapai Co., T. 11 N., R. 7 W., NW1/4, Sec. 36, elev. 3110'
Stat. 7	Ariz., Yavapai Co., T. 11 N., R. 7 W., NW1/4, Sec. 35, elev. 3070'
Stat. 8	Ariz., Yavapai Co., T. 11 N., R. 7 W., SE1/4, Sec. 34, elev. 3045'
Stat. 9	Ariz., Yavapai Co., T. 10 N., R. 7 W., NW1/4, Sec. 5, elev. 2915'
Stat. 10	Ariz., Yavapai Co., T. 10 N., R. 7 W., NW1/4, Sec. 7, elev. 2855'
Stat. 11	Ariz., Yavapai Co., T. 10 N., R. 8 W., SE1/4, Sec. 12, elev. 2810'
Stat. 12	Ariz., Yavapai Co., T. 10 N., R. 8 W., SW1/4, Sec. 14, elev. 2725' above Hwy. 93 bridge
Stat. 13	Ariz., Yavapai Co., T. 10 N., R. 8 W., NE1/4, Sec. 15, elev. 2675'

Cottonwood Creek

Stat. 14	Ariz., Yavapai Co., T. 11 N., R. 6 W., SE1/4, Sec. 30, elev. 3180' above confl. of Date Creek

Kirkland Creek

Stat. 15	Ariz., Yavapai Co., T. 12 N., R. 4 W., NW1/4, Sec. 28, elev. 4045', below Hwy. 89 bridge
Stat. 16	Ariz., Yavapai Co., T. 12 N., R. 4 W., NE1/4, Sec. 20, elev. 3980'
Stat. 17	Ariz., Yavapai Co., T. 12 N., R. 4 W., NE1/4, Sec. 7, elev. 3925'
Stat. 18	Ariz., Yavapai Co., T. 12 N., R. 5 W., NE1/4, Sec. 12, elev. 3870'
Stat. 19	Ariz., Yavapai Co., T. 13 N., R. 5 W., NE1/4, Sec. 20, elev. 3710'
Stat. 20	Ariz., Yavapai Co., T. 13 N., R. 5 W., NW1/4, Sec. 18, elev. 3610'
Stat. 21	Ariz., Yavapai Co., T. 13 N., R. 6 W., NW1/4, Sec. 14, elev. 3530'
Stat. 22	Ariz., Yavapai Co., T. 13 N., R. 6 W., SE1/4, Sec. 9, elev. 3490'
Stat. 23	Ariz., Yavapai Co., T. 13 N., R. 6 W., SE1/4, Sec. 5, elev. 3450'
Stat. 24	Ariz., Yavapai Co., T. 14 N., R. 7 W., SE1/4, Sec. 36, elev. 3180'
Stat. 25	Ariz., Yavapai Co., T. 14 N., R. 7 W., NE1/4, Sec. 34, elev. 2695'
Stat. 26	Ariz., Yavapai Co., T. 14 N., R. 7 W., SE1/4, Sec. 21, elev. 2640', above confl. of Sycamore Creek

Bland Creek

Stat. 27	Ariz., Yavapai Co., T. 13 N., R. 6 W., SE1/4, Sec. 16, elev. 3535'
Stat. 28	Ariz., Yavapai Co., T. 13 N., R. 6 W., NE1/4, Sec. 16, elev. 3515'

Sycamore Creek

Stat. 29	Ariz., Yavapai Co., T. 14 N., R. 7 W., SE1/4, Sec. 21, elev. 2640', above confl of Kirkland Creek

Santa Maria River

Stat. 30	Ariz., Yavapai Co., T. 14 N., R. 7 W., SW1/4, Sec. 21, elev. 2635', below confl. of Kirkland and Sycamore Creeks

Hassayampa River

Stat. 31 Ariz., Yavapai Co., T. 12 N., R. 3 W., NW1/4, Sec. 14, elev. 4115'

Stat. 32 Ariz., Yavapai Co., T. 12 N., R. 3 W., NE1/4, Sec. 22, elev. 4035'

Stat. 33 Ariz., Yavapai Co., T. 12 N., R. 3 W., NE1/4, Sec. 33, elev. 3900'

Stat. 34 Ariz., Yavapai Co., T. 11 N., R. 3 W., NE1/4, Sec. 9, elev. 3740'

Stat. 35 Ariz., Yavapai Co., T. 11 N., R. 3 W., SE1/4, Sec. 15, elev. 3655'

Stat. 36 Ariz., Yavapai Co., T. 11 N., R. 3 W., NW1/4, Sec. 26, elev. 3550'

Stat. 37 Ariz., Yavapai Co., T. 10 N., R. 3 W., NW1/4, Sec. 2, elev. 3445', above confl. of Milk Creek

Stat. 38 Ariz., Yavapai Co., T. 10 N., R. 3 W., NE1/4, Sec. 14, elev. 3320', above confl. of Blind Indian Creek

Stat. 39 Ariz., Yavapai Co., T. 10 N., R. 3 W., NE1/4, Sec. 26, elev. 3260', above confl. of Cherry Creek

Stat. 40 Ariz., Yavapai Co., T. 9 N., R. 3 W., NW1/4, Sec. 1, elev. 3020', above confl. of Oak Creek

Stat. 41 Ariz., Yavapai Co., T. 9 N., R. 3 W., SE1/4, Sec. 11, elev. 2870'

Stat. 42 Ariz., Yavapai Co., T. 9 N., R. 3 W., SW1/4, Sec. 15, elev. 2775'

Stat. 43 Ariz., Yavapai Co., T. 9 N., R. 3 W., SW1/4, Sec. 17, elev. 2650'

Stat. 44 Ariz., Yavapai Co., T. 9 N., R. 3 W., NE1/4, Sec. 30, elev. 2555'

Stat. 45 Ariz., Yavapai Co., T. 9 N., R. 4 W., NE1/4, Sec. 36, elev. 2465'

Stat. 46 Ariz., Yavapai Co., T. 8 N., R. 4 W., NE1/4, Sec. 3, elev. 2370'

Stat. 47 Ariz., Yavapai Co., T. 8 N., R. 4 W., SE1/4, Sec. 7, elev. 2250'

Stat. 48 Ariz., Yavapai Co., T. 8 N., R. 5 W., NE1/4, Sec. 14, elev. 2175'

Stat. 49 Ariz., Yavapai Co., T. 8 N., R. 5 W., SE1/4, Sec. 26, elev. 2095'

Stat. 50 Ariz., Maricopa Co., T. 7 N., R. 5 W., NE1/4, Sec. 12, elev. 2035', below Hwy 93 bridge at Wickenburg

Stat. 51 Ariz., Maricopa Co., T. 7 N., R. 4 W., NW1/4, Sec. 18, elev. 1985'

Stat. 52 Ariz., Maricopa Co., T. 7 N., R. 4 W., SW1/4, Sec. 20, elev. 1938'

Stat. 53 Ariz., Maricopa Co., T. 7 N., R. 4 W., NE1/4, Sec. 33, elev. 1875', at Roadside Park (Hwy. 93)

Stat. 54 Ariz., Maricopa Co., T. 6 N., R. 4 W., NW1/4, Sec. 3, elev. 1855'

Stat. 55 Ariz., Maricopa Co., T. 6 N., R. 4 W., NE1/4, Sec. 22, elev. 1775'

Stat. 56 Ariz., Maricopa Co., T. 6 N., R. 4 W., SW1/4, Sec. 34, elev. 1705'

Milk Creek

Stat. 57 Ariz., Yavapai Co., T. 11 N., R. 3 W., NW1/4, Sec. 36, elev. 3530'

Blind Indian Creek

Stat. 58 Ariz., Yavapai Co., T. 11 N., R. 2 W., SE1/4, Sec. 31, elev. 3580'

Minnehaha Creek

Stat. 59 Ariz., Yavapai Co., T. 10 N., R. 3 W., NW1/4, Sec. 24, elev. 3315', above confl. of Hassayampa River

Arrastre Creek

Stat. 60 Ariz., Yavapai Co., T. 10 N., R. 3 W., NW1/4, Sec. 23, elev. 3300', above confl. of Hassayampa River

Cottonwood Creek

Stat. 61 Ariz., Yavapai Co., T. 10 N., R. 3 W., SW1/4, Sec. 23, elev. 3350', above confl. of Spring Creek

Cherry Creek

Stat. 62	Ariz., Yavapai Co., T. 10 N., R. 3 W., NW1/4, Sec. 25, elev. 3285', above confl. of Hassayampa River

Oak Creek

Stat. 63	Ariz., Yavapai Co., T. 9 N., R. 3 W., NW1/4, Sec. 1, elev. 3035', above confl. of Hassayampa River

Bill Williams River

Stat. 64	Ariz., Yuma Co., T. 10 N., R. 13 W., NE1/4, Sec. 9, elev. 980', below Alamo Dam
Stat. 65	Ariz., Yuma Co., T. 10 N., R. 14 W., NE1/4, Sec. 14, elev. 880', at Lincoln Ranch
Stat. 66	Ariz., Yuma Co., T. 10 N., R. 14 W., NE1/4, Sec. 5, elev. 810'
Stat. 67	Ariz., Yuma Co., T. 10 N., R. 15 W., NW1/4, Sec. 12, elev. 760', below El Paso Natural Gas Pipeline
Stat. 68	Ariz., Yuma Co., T. 10 N., R. 15 W., SW1/4, Sec. 9, elev. 700'

Miscellaneous Collections

Bill Williams River

Ariz., Yuma Co., T. 10 N., R. 13 W., NW1/4, Sec. 8, elev 920'

Ariz., Yuma Co., T. 10 N., R. 13 W., SW1/4, Sec. 7, elev. 900'

Ariz., Yuma Co., T. 10 N., R. 14 W., NW1/4, Sec. 15, elev. 850'

Ariz., Yuma Co., T. 10 N., R. 15 W., NE1/4, Sec. 12, elev. 780', above El Paso Natural Gas Pipeline

Ally Wash

Ariz., Yavapai Co., T. 13 N., R. 6 W., NE1/4, Sec. 16, elev. 3515', above confl. of Bland Creek

Cottonwood Canyon

Ariz., Yavapai Co., T. 13 N., R. 5 W., SE1/4, Sec. 7, elev. 3685', 1.2 km above confl. of Kirkland Creek

Kirkland Creek

Ariz., Yavapai Co., T. 11 N., R. 4 W., SE1/4, Sec. 19, elev. 4400', below confl. of Miller and Model Creeks

Miller Creek

Ariz., Yavapai Co., T. 11 N., R. 4 W., SE1/4, Sec. 19, elev. 4410', above confl. of Model Creek

Model Creek

Ariz., Yavapai Co., T. 11 N., R. 5 W., SW1/4, Sec. 22, elev. 4605'

Ariz., Yavapai Co., T. 11 N., R. 4 W., SE1/4, Sec. 19, elev. 4405', above confl. of Miller Creek

Skull Valley Wash

Ariz., Yavapai Co., T. 13 N., R. 4 W., NE1/4, Sec. 7, elev. 4146'

Cellar Springs Creek

Ariz., Yavapai Co., T. 10 N., R 2 W., NE1/4, Sec. 6, elev. 3620', above confl. of Blind Indian Creek

Spring Creek

Ariz., Yavapai Co., T. 10 N., R. 3 W., SW1/4, Sec. 23, elev. 3350', above confl. of Cottonwood Creek.

Centennial Wash

Ariz., Yuma Co., T. 7 N., R. 11 W., SW1/4, Sec. 26, elev. 2010', at Centennial Dike

Martinez Creek

Ariz., Yavapai Co., T. 10 N., R. 6 W., SE1/4, Sec. 11, elev. 3260'

Alamo Lake

Ariz., Mohave Co., T. 11 N., R. 12 W., NE1/4, Sec. 8, elev. 1170'

APPENDIX 2. Distribution of aquatic insect taxa collected from the Bill Williams and Hassayampa River drainages, west-central Arizona, during March and April, 1980.

	Bill Williams		Hassayampa					
	Kirkland Creek	Bland Creek	Blind Indian Creek	Minnehaha Creek	Arrastre Creek	Cottonwood Creek	Cherry Creek	Hassayampa mainstream
Order Ephemeroptera								
Family Tricorythidae								
Tricorythodes sp					X			
Leptohypes sp.		X						
Family Baetidae								
Baetis spp.	X	X			X			
Baetis insignificans								X
Pseudocloeon sp.								X
Order Odonata								
Suborder Zygoptera								
Family Coenagrionidae								
Argia nr. *vivida*		X						
Order Plecoptera								
Family Capnidae[1]			X	X				X
Order Trichoptera								
Family Hydropsychidae								
Cheumatopsyche sp.		X			X			
Hydropsyche spp.	X					X		X
Family Helicopsychidae								
Helicopsyche sp.	X							

Appendix 2. Continued.

	Bill Williams		Hassayampa					
	Kirkland Creek	Bland Creek	Blind Indian Creek	Minnehaha Creek	Arrastre Creek	Cottonwood Creek	Cherry Creek	Hassayampa mainstream
Order Trichoptera								
Family Sericostomatidae								
Gumaga sp.		X						
Order Coleoptera								
Family Haliplidae								
Peltodytes simplex		X						
Family Dryopidae								
Helichus immsi	X				X			
Order Diptera								
Family Tipulidae								
Hexatoma sp.					X	X		
Family Culicidae								
Culiseta incidens		X						
Family Simuliidae								
indet. larvae	X					X		
Simulium sp.		X						X

Appendix 2. Continued.

	Bill Williams		Hassayampa					
	Kirkland Creek	Bland Creek	Blind Indian Creek	Minnehaha Creek	Arrastre Creek	Cottonwood Creek	Cherry Creek	Hassayampa mainstream
Order Diptera								
Family Chironomidae								
Subfamily Diamesinae								
Tribe Diamesini		X				X		X
Subfamily Orthocladiinae								
Orthocladius or *Cricotopus* spp.	X	X	X	X	X	X		X
Smittia sp.							X	
Subfamily Chironominae								
Paratendipes sp.					X			
Family Ceratopogonidae								
Palpomyia group[2]	X	X		X	X	X		
Family Stratiomyidae								
Euparyphus sp.		X			X			
Family Empidae					X			

[1,2] See taxonomic list of aquatic insects for probable or inclusive genera (Table 5)

APPENDIX 3. Distribution of fishes in the Bill Williams and Hassayampa River drainages, Maricopa, Yavapai, and Yuma Counties, Arizona.

	Santa Maria River	Sycamore Creek	Kirkland Creek	Date Creek	Alamo Lake	Bill Williams River	Hassayampa River and Tributaries
Family Clupeidae							
Dorosoma petenense - threadfin shad					X		
Family Cyprinidae							
Agosia chrysogaster - longfin dace	X	X	X	X			X
Carassius auratus - goldfish					X		
Cyprinus carpio - carp					X	X	
Gila robusta robusta-roundtail chub	X	X	X				
Notemigonus crysoleucus-golden shiner					X		
Notropis lutrensis - red shiner	X				X	X	
Pimephales promelas - fathead minnow							X
Family Catostomidae							
Catostomus insignis - Gila sucker	X	X	X				
Pantosteus clarki-Gila mountain-sucker	X	X	X				X
Family Ictaluridae							
Ictalurus melas - black bullhead	X		X		X		
Ictalurus natalis - yellow bullhead					X		
Ictalurus punctatus - channel catfish					X		
Pilodictis olivaris - flathead catfish					X		

Appendix 3. Continued.

	Santa Maria River	Sycamore Creek	Kirkland Creek	Date Creek	Alamo Lake	Bill Williams River	Hassayampa River and Tributaries
Family Poeciliidae							
Gambusia affinis affinis - mosquitofish					X	X	
Family Centrarchidae							
Chaenobryttus cyanellus - green sunfish	X	X	X		X	X	
Lepomis macrochirus - bluegill sunfish					X		
Lepomis microlophus - redear sunfish					X		
Lepomis microlophus x *Chaenobryttus cyanellus* - shellcracker					X		
Micropterus salmoides - largemouth bass					X		
Family Cichlidae							
Tilapia mossambica Mozambique mouthbrooder					X		

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